APPLICATION FOR PATENT

Title of Invention:

CIRCULAR CAVITY LASER

RELATED APPLICATIONS:

Provisional Patent Appl. Nr. 60/236,446

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CIRCULAR CAVITY LASER

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates generally to the field of mode discrimination means in laser cavities, and in particular, mode discrimination in macroscopic cavities wherein a vast number of modes may otherwise be sustained.

Description of the Related Art:

The present invention relates generally to the field of lasers and optical resonator design, and in particular, to the fields of disk and spherical lasers. Also, the invention relates to cavity structure designs that utilize multi-layer dielectric (MLD) thin film reflectors that provide a high degree of mode selection.

Laser cavities of the disk and spherical geometries have become an increasingly intensive field of research; in particular, for such lasers that are fabricated on a miniature or microscopic scale. In the latter case, the predominant means of cavity reflection is through total internal reflection (TIR), which provides an extremely high cavity Q. Such reflective means normally manifest in "whispering modes," which propagate at angles below the critical angle for TIR. These microdisk and microsphere lasers are very effective in cases involving evanescent coupling to an adjacent dielectric structure; however, they are known to contain a very large number of competing high-order modes.

In addition, the coupling of these whispering modes for useful work is difficult for applications not utilizing evanescent coupling.

In recent years, theoretical studies have been performed on the development of derivation methods for cylindrical and spherical multilayer structures, which are aimed at providing an accurate description of the reflection coefficients and modal characteristics of these cavities. These studies address circular confinement structures with cavity dimensions on the order of the wavelengths studied. However, none of these studies are found to address the issues of applying similar circular Bragg reflectors for larger cavities of the scale used for gas and larger solid state cavities. Furthermore, these previous studies also entertain only the use of conventional MLD filters, with a large real refractive index difference, n_H-n_L = $\Delta n > 1$, for the layer pairs, and with an accordingly small number of layers required for high reflection.

The use of interference structures to enable high spectral resolving power in reflecting coatings has been described by Emmett (US Pat. No. 4,925,259), wherein a very large number of alternating dielectric layers possessing a very small difference in refractive indices is used for application in high power flashlamps. The described coatings are utilized primarily for providing a high damage threshold to the high irradiance experienced in the flashlamp enclosure, as well as for obtaining a well-resolved pump wavelength for use in the described flashlamp.

The control of transverse modes in semiconductor lasers, primarily VCSEL's, has been reported by several research groups in the last decade. These latter reports utilize a circular Bragg grating structure as a complement to the planar Bragg mirrors of a conventional, high Q semiconductor cavity. Such circular Bragg gratings do not form the initial resonant cavity, but rather, aid in controlling relatively low Q, transverse modes of an existing Fabry-Perot structure. In such cases, the resultant control of transverse propagation may allow lowered thresholds, or enhanced stability.

Earlier, large-scale, laser designs of a circular geometry operated on very different principles than the microlasers, utilizing primarily gas laser mediums and metallic reflectors. In these earlier designs, optical power could be coupled for useful work at the center of the cavity, such as for isotope separation, or by using a conical reflector. Since, in these latter cases, laser modes that concentrated energy at the cavity's center were needed, some means for blocking the whispering-type modes was generally required. Such mode suppression was usually accomplished through radial stops; however, these stops only provided the most rudimentary mode control, in addition to hampering the efficient operation of the laser. Because of such issues, disk and spherical lasers have not supplanted standard linear lasers for any applications requiring substantial optical power or a high degree of mode selection.

SUMMARY OF THE INVENTION

A novel laser apparatus has been developed for use in such applications as lasers and light amplifiers in general. The laser developed comprises a cavity mirror structure that provides a single surface of revolution. The cavity volume is defined by this surface of revolution, and contains the gain medium. Unlike prior art disk and/or spherical lasers possessing circular cavities, the present invention does not rely on total internal reflection (TIR) or metallic reflectors to provide a high cavity Q-factor (and a broad range of high-order modes). The laser design of the present invention avoids use of these cavity confinement methods. In the optical resonator of the present invention, interference-based multilayer dielectric (MLD) reflectors are constructed that can possess unusually narrow reflection peaks, corresponding to a degree of finesse (finesse designating interference-based resolving power) usually associated with MLD transmission filters of the Fabry-Perot type. The high-finesse MLD reflectors of the present invention conform to the surface of revolution of the cavity mirror structure, allowing a high degree of angle-dependence for selective containment of cavity modes. These filters are disposed in such a way as to allow preferred low order modes (lower order modes being represented in the present disclosure as those corresponding to near normal incidence radiation) and suppression of parasitic modes while allowing a high cavity Q factor for the modes selected.

For a multi-layer dielectric (MLD) coating consisting of alternating layers, where all layers have an optical thickness equal to a quarter-wave of light at the wavelength of interest, the reflectance may be described according to:

$$R = \left[\frac{1 - (n_H/n_L)^{2p}\,(n_H^2/n_L)}{1 + (n_H/n_L)^{2p}\,(n_H^2/n_L)} \right]^2 \qquad (1)$$

wherein the index of refraction for the substrate is n_s, the two layer indices are n_H (high index) and n_L (low index), and the number of pairs of alternating layers is **p**. As is evidenced by equation (1), a higher reflectance may be achieved through the implementation of a greater difference in refractive index $\Delta n = | n_2 - n_l |$. High reflectance is thus normally achieved by maintaining Δn at a relatively high value. However, as equation (1) suggests, high reflectance may also be achieved by depositing many layer pairs possessing a relatively low difference in their refractive indices. As the index difference decreases, many more pairs of alternating layers must be deposited to maintain reasonable reflectance. At the same time, this latter approach will result in a decrease in the bandwidth of light reflected by the resultant coating. The present invention utilizes MLD coatings which obtain high reflectance from an unusually low Δn; this is accomplished by maintaining a high degree of control over the properties of each layer through an unusually high number of iterations, **p,** of the layer pair. With well-controlled film characteristics, the reflectance of the resulting MLD coating is found to have a quite narrow bandwidth, typically in the order of nanometers.

A characteristic of the MLD coatings utilized in the present invention is the angle-dependence of the reflection peak. As the MLD coating is irradiated at increasingly oblique angles of incidence, the spectrally narrow reflection peak will be shifted toward increasingly shorter wavelengths. While the degree of this latter peak shift will depend on such issues as phase dispersion and the change in optical admittance with increasingly oblique incidence, the fractional shift in the peak transmittance will change generally with the phase thickness shift. As such, the fractional shift in peak transmittance will be slightly less than cos θ, where θ is the angle from normal incidence. As the angle of incidence, θ, increases, the magnitude of the reflectance peak will generally decrease, as well.

The aforementioned characteristics of these high-finesse MLD coatings are utilized in the preferred embodiments of the present invention. In accordance with the illustrated preferred embodiments, a novel laser cavity structure is disclosed herein that effectively utilizes the sensitivity of the aforementioned coatings to angle-of-incidence when these same coatings are irradiated with quasi-monochromatic light. This is normally accomplished through the use of a cavity mirror that conforms to a single surface of revolution. High confinement is achieved through novel use of the highly angle-dependent MLD reflectors. Thus, instead of utilizing TIR or metal films, which both provide wide acceptance angles to high order cavity modes, the present invention utilizes external reflection and narrow acceptance angles to increase the stability of selected, lower order, cavity modes.

Because the present invention does not rely on TIR or metallic films to provide high confinement for various laser modes, it is designed with a fundamentally different set of requirements for the refractive indices of its individual components. In contrast to the disk and spherical lasers of the prior art, the gain medium – or, equivalently, the volume in which it resides – in lasers of the present invention should possess an effective refractive index, n_G, lower than that of the immediately surrounding medium. As such, the high index layers of the MLD of the present invention must have a refractive index, n_H, greater than that of the gain volume.

In one preferred embodiment, the present invention provides a laser cavity structure that does not require a partially reflective mirror or external optics to efficiently couple laser light to a work piece or various process media. Instead, the laser cavity structure disclosed herein allows photo-absorbing media to be introduced through the center of the cavity, so that energy not absorbed by the photo-absorbing media may contribute back to the energy stored inside the cavity. According to this aspect, the irradiation of photo-absorbing media may also be rendered highly uniform, and is well suited for media of substantially circular symmetry.

In another embodiment, the invention provides a unique configuration for coupling laser radiation from the edge of the spherical and disk lasers described, as the mode selection provided allows efficient coupling of a low-divergence beam from the cavity edge. Other objects of the present invention follow.

One objective of the present invention is to provide a laser cavity structure that allows high thermal stability.

Another objective of the present invention is to provide a disk or spherical laser cavity structure that discourages the establishment of whispering modes

Another object of the present invention is to provide a laser cavity structure which allows mode selection through the use of all-dielectric reflectors of unusually high finesse.

Yet another object of the present invention is to increase the stability of conventional laser cavity structures through the suppression of walk-off modes.

Another object of the present invention is to provide a laser cavity structure that allows a low threshold to lasing.

Another object of the present invention is to provide a means for irradiating a photo-absorbing medium from a continuous 360-degree periphery.

Another object of the present invention is to provide a laser cavity structure that allows efficient and reliable mechanical design.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a delimited cross-sectional view of a thin film design for a MLD used in the preferred embodiment.

FIG. 2 is a reflectance curve for an MLD coating fabricated in accordance with the embodiments set forth in FIG. 1., showing normal incidence and tilted reflectance in the region of 300nm to 400nm.

FIG. 3 is a sectional top view of the invention in its first preferred embodiment.

FIG. 4 is a sectional side view of the invention constructed as a spherical cavity laser.

FIG. 5 is a sectional side view of the invention constructed as a cylindrical cavity laser.

FIG. 6 is a sectional top view of the invention in one of its embodiments, showing laser emission coupled from the edge of the cavity.

FIG. 7 is a sectional top view of the invention in another of its embodiments, wherein the cavity is pumped by an external light source.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description and **FIGS. 1** through **7** of the drawings depict various embodiments of the present invention. The embodiments set forth herein are provided to convey the scope of the invention to those skilled in the art. While the invention will be described in conjunction with the preferred embodiments, various alternative embodiments to the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein. Like numerals are used for like and corresponding parts of the various drawings.

In **FIG. 1** is a repeated scheme for the build-up of a high-reflectance MLD. The MLD contains **p** quarter-wave pairs, each consisting of a low index layer **(14)** and a high index layer **(15)**. The substrate **(1)** provides the surface of revolution onto which the MLD is deposited, thus forming the gas cavity laser referred to in **FIGS. 3-7**. Each pair of quarter-wave layers **(14)** and **(15)** share a small refractive index difference, Δn, which is typically less than 0.2. The number of quarter-wave pairs, **p**, will typically be greater than 50 to maintain high reflectance. The quarter-wave pairs may be deposited sequentially to achieve MLD's containing hundreds of layers. Materials used will depend upon the spectral region desired for lasing action. In many cases the small difference in real refractive index, Δn, may be achieved by making substitutions into the matrix of a parent material.

For instance, ZrO_2 may be deposited as the parent material by ion beam sputtering, thereby forming one of the quarter-wave layers. Subsequently, the second layer material may then be formed using the same process, while co-sputtering a second material, such as TiO_2, from a separate target in the same process chamber, resulting in the second layer being a mixture of the two oxides. As a result, the refractive index of the second layer may be controllably rendered slightly higher than that of the first layer; this, through the well-controlled addition of TiO_2 to a ZrO_2 matrix. The MLD, as shown in **FIG. 1**, may also be constructed with additional thin film structures incorporated for performing additional functions, such as anti-reflection coatings or secondary reflectors, and so forth. However, to achieve the finesse required in the present invention, the MLD design chosen for the cavity mirror must incorporate a high number of quarter-wave pair iterations, accompanied by an unusually small index difference, Δn.

In **FIG. 2** are reflectance curves, in wavelength λ vs. % reflectance, for an MLD reflector fabricated according to the design set forth in **FIG. 1**, for light incident approximately normal to the substrate. The reflectance peak of the MLD reflector at normal incidence, as given by the solid line **(2)**, is an example of the narrow full-width-half-max (FWHM) achieved with low Δn. The reflectance peaks of **FIG. 2** is obtained from a MLD reflector containing ninety pairs (**p**=90) of the quarter-wave layers, with the index difference of the pair, Δn=0.04. A topmost high-index layer **(19)** would typically be deposited to give maximum reflectance, resulting in an odd number of layers (in this case, 181 layers). The dashed line **(3)** in **FIG. 2** is the reflectance peak for the same MLD reflector when irradiated with light at an angle of 15° from normal incidence. The spectral shift between

the two reflectance peaks of FIG. 2 is found to be approximately $\lambda_0 - \lambda_1 = \Delta\lambda = 5$ nm, while the magnitude of p-polarization peak reflectance is also found to drop from 95% to 94%. The magnitude of the peak reflectance may be increased through an increase in **p**; and, as peak reflectance increases, the latter 1% percent drop becomes an increasingly decisive factor in determining cavity Q, and mode selection, within the laser cavity. A more narrow, or broad, FWHM **(16)** may be obtained by varying Δn according to the previously described relationships. In addition to the narrow FWHM, another useful characteristic of this MLD design, when incorporated in the present invention, is the pointed shape of the peak, as this pointed shape allows a more narrowly defined peak reflectance. The utility of these characteristics will become apparent when discussed in conjunction with the embodiments of **FIGS. 3-7**.

In **FIG. 3**, the present invention is shown in its first preferred embodiment. The substrate **(1)** provides the structure by which the surface of revolution, with axis of circular symmetry **(9)**, is defined. In the embodiments of **FIGS. 3-7**, this surface of revolution will be identical to the interface between the substrate **(1)** and the MLD reflector **(5)**. The MLD reflector **(5)**, as described in **FIGS. 1-2**, conforms to this surface of revolution and modifies its reflective characteristics. The gain medium for the laser is contained within the cavity interior **(4)**, formed by the substrate and integral MLD reflector. As such, if a fluorescent event occurs within the gain medium, its confinement within the cavity is very much altered through the incorporation of the previously set forth MLD. The MLD limits the bandwidth of the laser emission, first through the interference filtering of the normal incidence emission, as practiced in the prior art. However the circular geometry

of the present invention, combined with the high angle-dependence of the MLD reflector, as described in **FIGS. 1-2**, requires that emission from the fluorescent event also propagate within a narrowly defined solid angle, if it is to be reflected back into the cavity interior **(4)**. Propagation which occurs outside this solid angle, such as indicated by solid line **(6)**, will be allowed to transmit outside of the cavity interior **(4)**, thereby avoiding the establishment of laser modes for such off-angle propagation. In the geometries described, these highly angle-dependent MLD reflectors thereby become a means of mode selection. The zig-zag line **(7)** which depicts the direction of mode propagation is only for demonstration, but indicates that the concentration of allowed modes is at or near normal incidence. The precise angle of the dominant mode will be determined by such design considerations as the preferred angle-of-incidence, the fluorescence spectra of the gain medium, the type of coupling desired, etc.

In the laser cavity structure of the present invention, confinement of the laser modes to paths that are at or near to normal incidence allows several unique coupling configurations. One such configuration is shown in **FIG. 3**, wherein laser radiation is coupled from the laser by introducing the media to be processed into the center of the laser cavity. This may be accomplished through implementation of a tube **(8)**, which separates the gain medium from the process media passing through the tube interior, thereby providing a process volume within the cavity. The latter embodiment will be particularly effective in the processing of media that possess low absorption cross-sections, such as gases and vapors. Alternatively, the central coupling structure designated by the tube **(8)** may instead contain a cone-shaped optical element for

extraction of laser light from the center of the cavity as has been described in numerous papers and patents of the prior art.

The cross-sectional figure of the cavity mirror may be designed variously, dependent upon the type of gain medium and lasing action required. In **FIG. 4**, the surface of revolution possesses a cross-sectional figure with a radius of curvature equivalent to that of the surface of revolution as viewed from the top in **FIG. 3**, thereby rendering it a spherical section. In this embodiment, laser emission is confined to propagate through a small volume **(17)** located at the center of the spherical mirror, intersected by the axis of circular symmetry **(9)**, thereby allowing an unusually high power density within this small volume.

Another embodiment of the present invention is presented in **FIG. 5**, in which the cross-sectional figure of the surface of revolution– again, identical to the MLD/substrate interface – is straight, thereby rendering the surface of revolution a cylinder. The cylindrical shape of the laser cavity structure in the latter embodiment serves to demonstrate an added utility that is realized with the incorporation of the described MLD's. Unlike the cavity geometries of the prior art, linear and other, which use relatively low-finesse reflectors, the present invention allows the stability associated with a particular cavity mirror selection to be increased. Whereas flat (or cylindrical) cavity mirrors will typically support parasitic "walk-off" modes which can decrease the overall Q-factor of the laser cavity, these same modes, such as exemplified by propagation

direction **(6)** in **FIG. 5**, will be discouraged due to the low reflectivity of the cavity mirrors at these angles.

In an alternative embodiment of the present invention, laser radiation may also be coupled out of the laser cavity through the edge of the cavity, as in **FIG. 6**. This latter coupling may be accomplished by selectively removing or preventing the MLD deposition – through etching, masking, etc. – so as to provide an effective aperture **(10)** through which radiation may transmit. Benefits of the invention, as set forth in the embodiments of **FIG. 6**, include the ability to combine a high degree of mode selection with an unusually high cavity Q (and commensurately low threshold).

In **FIG. 7** is another embodiment of the present invention that allows for edge pumping of the circular cavity. The laser cavities described in the present invention may comprise gas, solid, or liquid gain media, and may be pumped by any of the compatible methods described in the art, such as by a discharge. Also, the present invention allows for a unique method of optical pumping. Because of the reflectance and, inversely, the transmission characteristics of the high-finesse MLD's of the present invention, lasers of the present invention may easily be pumped with laser radiation which corresponds to the peak absorption region of the gain medium's absorption spectrum. It is possible in the present invention to efficiently couple in the pump radiation through the cavity mirror and MLD. In this manner, diode lasers could be positioned around the periphery of the cavity mirror.

It should be noted that, in embodiments of the present invention where the laser cavity is fabricated with a disk-like aspect, thermal stability is typically more easily obtained than in other laser cavities. This latter advantage is due to the ability to effectively heat-sink the cavity through its planar sides – as indicated by dashed lines **(18)** in **FIGS. 4-5** – as these surfaces need not be transparent. In fact, these surfaces can possess any of a number of reflecting, absorbing, or scattering characteristics, depending on the application. The ability to heat-sink these cavities can be particularly important in the case that the gain medium is solid state. Heat-sinking, in such a case, may also be performed effectively through the cavity mirror, as long as the outer layers of the cavity mirror are specified so as to prevent any possible TIR of unwanted laser wavelengths. If the laser cavity structure of the present invention is to be operated in an ambient medium which possesses a refractive index, n_A, substantially lower than n_G, then an absorbing and/or scattering layer is preferably utilized externally to the MLD. This latter use of an absorbing and/or scattering layer serves to prevent specular reflection of unwanted cavity emissions back through the MLD to re-enter the gain volume. Such measures could be implemented in the case that the gain medium is solid state.

It is not intended that the MLD reflector be restricted to the embodiments of **FIG.1**, as the latter embodiments are presented primarily for the purpose of teaching the invention. The MLD implemented in a particular embodiment will depend on its particular requirements. The MLD may comprise organic or inorganic materials, or a combination of both. The design of the MLD reflector may vary considerably, as well. For instance, certain layer pairs within the MLD may possess a much higher Δn without appreciably

increasing the FWHM of **FIG. 2**. The thin film materials utilized may possess amorphous or crystalline microstructures; and as such, may be optically isotropic, uniaxial or biaxial, depending upon the precise transmission characteristics of the MLD reflector. The MLD reflector may, in some applications, be designed for peak reflectance at a relatively large angle of incidence. Various other functions may also be incorporated into the MLD design, such as an anti-reflection coating, or the transmission of a particular fluorescence peak.

It should also be noted that the embodiments of **FIGS. 3-4** do not require that the described spherical cavity laser be restricted to any particular major spherical section. In fact, the cavity structure sectional view of **FIG. 4** may as easily describe operation of a cavity structure that is not truncated at all, so that the cavity is a complete sphere. Also, the MLD described herein may, in many circumstances, be deposited on the external surface of the substrate, therein defining the required surface of revolution. In these latter circumstances, the substrate would reside within the cavity interior, and hence would need to be quite transparent to the desired wavelengths. Such a case might be when the required surface of revolution is the external surface of a sphere, which is composed of a laser glass or crystalline material.

The present invention is seen to have potential applications in several areas. One such application would be in the treatment of optical fibers or optical fiber preforms, where the fiber or preform could be passed through the center of a laser cavity similar to that described in **FIG. 3**. Another potential application could arise in the general field of

vapor deposition, where various vapors or gases might be ionized, heated, or otherwise altered by passing through the process volume of **FIG. 3**.

The preceding description provides an laser cavity structure that may be operated as a laser, optical amplifier, or other, optically resonating, device. Although the present invention has been described in detail with reference to the embodiments shown in the drawings, it is not intended that the invention be restricted to such embodiments. It will be apparent to one practiced in the art that various departures from the foregoing description and drawings may be made without departure from the scope or spirit of the invention.

ABSTRACT

A novel laser apparatus is disclosed which pertains to laser resonator geometries possessing circular symmetry, such as in the case of disk or spherical lasers. The disclosed invention utilizes multi-layer dielectric (MLD) thin film reflectors of many layer pairs of very small refractive index difference, the MLD deposited on a surface of revolution, thereby forming an optical cavity. These dielectric reflectors are disposed in such a way as to allow selection of preferred low order modes and suppression of parasitic modes while allowing a high cavity Q factor for preferred modes. The invention disclosed, in its preferred embodiments, is seen as particularly useful in applications requiring high efficiency in the production and coupling of coherent radiation. This is accomplished in a cavity design that is relatively compact and economical.

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Amendment A

7

APPLICATION FOR PATENT

Title of Invention:

<u>CAVITY</u> (insert)

CIRCULAR LASER

(text in brackets is for deletion; text underlined is to be added; text in parentheses is direction only)

RELATED APPLICATIONS:

Provisional Patent Appl. Nr. 60/236,446

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Assignees: none

CIRCULAR LASER

BACKGROUND OF THE INVENTION

Field of the Invention:

(delete)

The present invention relates generally to the field of mode discrimination means in [disk and spherical] laser cavities, and in particular, mode discrimination in macroscopic cavities wherein a vast number of modes may otherwise be sustained.

Description of the Related Art:

(change)

The present invention relates generally to the field of lasers and optical resonator design, and in particular, to the fields of disk and spherical lasers. Also, the invention relates to cavity structure [resonator] designs that utilize multi-layer dielectric (MLD) thin film reflectors that provide a high degree of mode selection.

(change)

Laser cavities [resonators] of the disk and spherical geometries have become an increasingly intensive field of research; in particular, for such lasers that are fabricated on a miniature or microscopic scale. In the latter case, the predominant means of cavity reflection is through total internal reflection (TIR), which provides an extremely high cavity Q. Such reflective means normally manifest in "whispering modes," which propagate at angles below the critical angle for TIR. These microdisk and microsphere

(change)

lasers [resonators] are very effective in cases involving evanescent coupling to an adjacent dielectric structure; however, they are known to contain a very large number of

competing high-order modes. In addition, the coupling of these whispering modes for useful work is difficult for applications not utilizing evanescent [propagation] coupling (change)

In recent years, theoretical studies have been performed on the development of derivation methods for cylindrical and spherical multilayer structures, which are aimed at providing an accurate description of the reflection coefficients and modal characteristics of these cavities. These studies address circular confinement structures with cavity dimensions on the order of the wavelengths studied. However, none of these studies are found to address the issues of applying [such] similar circular Bragg reflectors for larger cavities (change) (insert) of the scale used for gas and larger solid state cavities. [These] Furthermore, these previous studies also entertain (change) only the use of conventional MLD filters, with a large real refractive index difference, $n_H - n_L = \Delta n > 1$, for the layer pairs, and with an accordingly small number of layers required for high reflection.

→(insert new paragraph regarding Emmett, in Amendment A)

The control of transverse modes in semiconductor lasers, primarily VCSEL's, has been reported by several research groups in the last decade. These latter reports utilize a circular Bragg grating structure as a complement to the planar Bragg mirrors of a conventional, high Q semiconductor cavity. Such circular Bragg gratings do not form the initial resonant cavity, but rather, aid in controlling relatively low Q, transverse modes of an existing Fabry-Perot structure. In such cases, the resultant control of transverse propagation may allow lowered thresholds, or enhanced stability.

(change) Earlier, large-scale, [resonator] laser designs of a circular geometry operated on very different principles than the microlasers, utilizing primarily gas laser mediums and

metallic reflectors. In these earlier designs, optical power could be coupled for useful work at the center of the cavity, such as for isotope separation, or by using a conical reflector. Since, in these latter cases, laser modes that concentrated energy at the cavity's center were needed, some means for blocking the whispering-type modes was generally required. Such mode suppression was usually accomplished through radial stops; however, these stops only provided the most rudimentary mode control, in addition to hampering the efficient operation of the laser. Because of such issues, disk and spherical
(change) lasers linear lasers (change)
[resonators] have not supplanted standard [resonators] for any applications requiring substantial optical power or a high degree of mode selection.

SUMMARY OF THE INVENTION

(change) laser apparatus (change)
A novel [optical resonator] has been developed for use in such applications as
laser (change) cavity
lasers and light amplifiers in general. The [resonator] developed comprises a [resonator] mirror structure that provides a single surface of revolution. The cavity volume is
medium (change)
defined by this surface of revolution, and contains the gain [media]. Unlike prior art disk and/or spherical lasers possessing circular cavities, the present invention does not rely on total internal reflection (TIR) or metallic reflectors to provide a high cavity Q-factor (and
(delete) laser (change)
a broad range of high-order [propagation] modes). The [resonator] design of the present invention avoids use of these cavity confinement methods. In the optical resonator of the present invention, interference-based multilayer dielectric (MLD) reflectors are
(change) (change)
[developed that] possess unusually narrow reflection peaks[.] These narrow bandwidths
constructed that can , corresponding to

 (insert)

(finesse designating interference-based resolving power)

provide[s] a degree of finesse usually associated with MLD transmission filters of the Fabry-Perot type. The high-finesse MLD reflectors of the present invention conform to the surface of revolution of the cavity [resonator] mirror structure, allowing a high degree of (change) angle-dependence for selective containment of cavity [resonator] modes. These filters are (change) disposed in such a way as to allow (change) [selection of] preferred low order modes (lower order modes being represented in the present disclosure as those corresponding to near normal incidence radiation) (insert) and suppression of parasitic modes while allowing a high cavity Q factor for the modes selected.

For a multi-layer dielectric (MLD) coating consisting of alternating layers, where all layers have an optical thickness equal to a quarter-wave of light at the wavelength of interest, the reflectance may be described according to:

$$R = \left[\frac{1 - (n_H/n_L)^{2p} (n_H^2/n_L)}{1 + (n_H/n_L)^{2p} (n_H^2/n_L)} \right]^2 \qquad (1)$$

wherein the index of refraction for the substrate is n_s, the two layer indices are n_H (high index) and n_L (low index), and the number of pairs of alternating layers is **p**. As is evidenced by equation (1), a higher reflectance may be achieved through the implementation of a greater difference in refractive index $\Delta n = | n_2 - n_1 |$. High reflectance is thus normally achieved by maintaining Δn at a relatively high value. However, as equation (1) suggests, high reflectance may also be achieved by depositing many layer pairs possessing a relatively low difference in their refractive indices. As the index difference decreases, many more pairs of alternating layers must be deposited to maintain

reasonable reflectance. At the same time, this latter approach will result in a decrease in the bandwidth of light reflected by the resultant coating. The present invention utilizes MLD coatings which obtain high reflectance from an unusually low Δn; this is accomplished by maintaining a high degree of control over the properties of each layer through an unusually high number of iterations, **p,** of the layer pair. With well-controlled film characteristics, the reflectance of the resulting MLD coating is found to have a quite narrow bandwidth, typically in the order of nanometers.

A characteristic of the MLD coatings utilized in the present invention is the angle-dependence of the reflection peak. As the MLD coating is irradiated at increasingly oblique angles of incidence, the spectrally narrow reflection peak will be shifted toward increasingly shorter wavelengths. While the degree of this latter peak shift will depend on such issues as phase dispersion and the change in optical admittance with increasingly oblique incidence, the fractional shift in the peak transmittance will change generally with the phase thickness shift. As such, the fractional shift in peak transmittance will be slightly less than cos θ, where θ is the angle from normal incidence. As the angle of incidence, θ, increases, the magnitude of the reflectance peak [for the p polarization] will (delete)

(change) [decline] as well.
generally decrease

The aforementioned characteristics of these high-finesse MLD coatings are utilized in the preferred embodiments of the present invention. In accordance with the
cavity structure (change)
illustrated preferred embodiments, a novel laser [resonator] [has been developed] that
is disclosed herein
effectively utilizes the sensitivity of the aforementioned coatings to angle-of-incidence

(insert)

when these same coatings are irradiated with quasi-monochromatic light. This is normally

(change) cavity

accomplished through the use of a [resonator] mirror that conforms to a single surface of

novel (insert)

revolution. High confinement is achieved through use of the highly angle-dependent

(delete)

MLD reflectors [developed in the present invention]. Thus, instead of utilizing TIR or

cavity (change)

metal films, which both provide wide acceptance angles to high order [resonator] modes, the present invention utilizes external reflection and narrow acceptance angles to increase

cavity

the stability of selected, lower order, [resonator] modes. (change)

Because the present invention does not rely on TIR or metallic films to provide high confinement for various laser modes, it is designed with a fundamentally different set of requirements for the refractive indices of its individual components. In contrast to

medium (change)

the disk and spherical lasers of the prior art, the gain [media] – or, equivalently, the volume in which it resides – in lasers of the present invention should possess an effective refractive index, n_G, lower than that of the immediately surrounding medium. As such, the high index layers of the MLD of the present invention must have a refractive index, n_H, greater than that of the gain volume.

(change)

cavity structure

In one preferred embodiment, the present invention provides a laser [resonator] that

does not require a partially reflective mirror or external optics to efficiently couple laser (change)

(change) various process media (change) cavity structure disclosed

light to a work piece or [medium]. Instead, the laser [resonator developed] herein allows [a

(change) photo-absorbing medium] to be introduced through the center of the cavity, so that energy

photo-absorbing media

media (change)

not absorbed by the photo-absorbing [medium] may contribute back to the energy stored

inside the cavity. According to this aspect, the irradiation of [a photo-absorbing medium] (change)

photo-absorbing media

may also be rendered highly uniform, and is well suited for media of substantially circular symmetry.

In another embodiment, the invention provides a unique configuration for coupling laser radiation from the edge of the spherical and disk lasers described, as the mode selection provided allows efficient coupling of a low-divergence beam from the cavity edge. Other objects of the present invention follow.

cavity (change)

(delete)

One objective of the present invention is to provide a laser [resonator] structure that allows [unusually] high thermal stability.

(change) cavity structure

Another objective of the present invention is to provide a disk or spherical laser [resonator] that discourages the establishment of whispering modes

(change) cavity structure

Another object of the present invention is to provide a laser [resonator] which allows mode selection through the use of all-dielectric reflectors of unusually high finesse

(change) cavity structures

Yet another object of the present invention is to increase the stability of conventional laser [resonators] through the suppression of walk-off modes.

cavity structure (change)

Another object of the present invention is to provide a laser [resonator] that allows a low threshold to lasing.

Another object of the present invention is to provide a means for irradiating a photo-absorbing medium from a continuous 360-degree periphery.

(change)
cavity structure

Another object of the present invention is to provide a laser [resonator] that allows efficient and reliable mechanical design.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a delimited cross-sectional view of a thin film design for a MLD used in the preferred embodiment.

FIG. 2 is a reflectance curve for an MLD coating fabricated in accordance with the embodiments set forth in FIG. 1., showing normal incidence and tilted reflectance in the region of 300nm to 400nm.

FIG. 3 is a sectional top view of the invention in its first preferred embodiment.

(change)
cavity laser

FIG. 4 is a sectional side view of the invention constructed as a spherical [resonator]

(change)
cavity laser

FIG. 5 is a sectional side view of the invention constructed as a cylindrical [resonator].

FIG. 6 is a sectional top view of the invention in one of its embodiments, showing laser emission coupled from the edge of the cavity.

FIG. 7 is a sectional top view of the invention in another of its embodiments, wherein the cavity is pumped by an external light source.

DESCRIPTION OF THE PREFERRED

EMBODIMENTS

The following description and **FIGS. 1** through **7** of the drawings depict various embodiments of the present invention. The embodiments set forth herein are provided to convey the scope of the invention to those skilled in the art. While the invention will be described in conjunction with the preferred embodiments, various alternative embodiments to the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein. Like numerals are used for like and corresponding parts of the various drawings.

In **FIG. 1** is a repeated scheme for the build-up of a high-reflectance MLD. The MLD contains **p** quarter-wave pairs, each consisting of a low index layer **(14)** and a high index layer **(15)**. The substrate **(1)** provides the surface of revolution onto which the MLD is deposited, thus forming the [resonator] gas cavity laser (change) referred to in **FIGS. 3-7**. Each pair of quarter-wave layers **(14)** and **(15)** share a small refractive index difference, Δn, which is

typically less than 0.2. The number of quarter-wave pairs, **p**, will typically be greater than 50 to maintain high reflectance. The quarter-wave pairs may be deposited sequentially to achieve MLD's containing hundreds of layers. Materials used will depend upon the spectral region desired for lasing action. In many cases the small difference in real refractive index, Δn, may be achieved by making substitutions into the matrix of a parent material.

For instance, ZrO_2 may be deposited as the parent material by ion beam sputtering, thereby forming one of the quarter-wave layers. Subsequently, the second layer material may then be formed using the same process, while co-sputtering a second material, such as TiO_2, from a separate target in the same process chamber, resulting in the second layer being a mixture of the two oxides. As a result, the refractive index of the second layer may be controllably rendered slightly higher than that of the first layer; this, through the well-controlled addition of TiO_2 to a ZrO_2 matrix. The MLD, as shown in **FIG. 1**, may also be constructed with additional thin film structures incorporated for
<u>coatings or</u> (change)
performing additional functions, such as anti-reflection [coatings,] secondary reflectors, and so forth. However, to achieve the finesse required in the present invention, the MLD
<u>cavity</u> (change)
design chosen for the [resonator] mirror must incorporate a high number of quarter-wave pair iterations, accompanied by an unusually small index difference, Δn.

(change) <u>are reflectance curves, in wavelength λ vs. % reflectance</u>

In **FIG. 2** [is a reflectance curve] for an MLD reflector fabricated according to the
<u>approximately</u> (insert) <u>peak</u> (insert)
design set forth in **FIG. 1**, for light incident normal to the substrate. The reflectance of the MLD reflector at normal incidence, as given by the solid line **(2)**, [demonstrates] the (change)
<u>is an example of</u>

achieved (change) peaks (change)

narrow full-width-half-max (FWHM) [achievable] with low Δn. The reflectance [curve] of

(change) obtained (change)

FIG. 2 is [derived] from [an] MLD reflector containing ninety pairs (**p**=90) of the quarter-

a difference (change)

wave layers, with the index [split] of the pair, Δn=0.04. A topmost high-index layer **(19)** would typically be deposited to give maximum reflectance, resulting in an odd number of

line (change) peak (change)

layers (in this case, 181 layers). The dashed [curve] **(3)** in **FIG. 2** is the reflectance [curve] for the same MLD reflector when irradiated with light at an angle of 15° from normal

(change) - between the two reflectance peaks. of FIG. 2

incidence. The spectral shift [in the reflectance peak] is found to be approximately [Δλ=5 nm]

$\lambda_0' - \lambda_1 = \Delta\lambda = 5nm$ (change)

while the magnitude of p-polarization peak reflectance is also found to drop from 95% to 94%. The magnitude of the peak reflectance may be increased through an increase in **p**; and, as peak reflectance increases, the latter 1% percent drop becomes an increasingly decisive factor in determining cavity Q, and mode selection, within the

laser cavity (change)

[resonator]. A more narrow, or broad, FWHM **(16)** may be obtained by varying Δn according to the previously described relationships. In addition to the narrow FWHM, another useful characteristic of this MLD design, when incorporated in the present invention, is the pointed shape of the peak, as this pointed shape allows a more narrowly defined peak reflectance. The utility of these characteristics will become apparent when discussed in conjunction with the embodiments of **FIGS. 3-7**.

In **FIG. 3**, the present invention is shown in its first preferred embodiment. The substrate **(1)** provides the structure by which the surface of revolution, with axis of circular symmetry **(9)**, is defined. In the embodiments of **FIGS. 3-7**, this surface of revolution will be identical to the interface between the substrate **(1)** and the MLD reflector **(5)**. The MLD reflector **(5)**, as described in **FIGS. 1-2**, conforms to this surface

of revolution and modifies its reflective characteristics. The gain [media] medium (change) for the laser is contained within the cavity [volume] interior (change) **(4)**, formed by the substrate and integral MLD reflector. As such, if a fluorescent event occurs within the gain [media] medium (change), its confinement within the cavity is very much altered through the incorporation of the previously set forth MLD. The MLD limits the bandwidth of the laser emission, first through the interference filtering of the normal incidence emission, as practiced in the prior art. However the circular geometry of the present invention, combined with the [extreme] high (change) angle-dependence of the MLD reflector, as described in **FIGS. 1-2**, requires that emission from the fluorescent event also propagate within a narrowly defined solid angle, if it is to be reflected back into the cavity [volume] interior (change) **(4)**. Propagation which occurs outside this solid angle, such as indicated by solid line **(6)**, will be allowed to transmit outside of the cavity [volume] interior (change) **(4)**, thereby avoiding the establishment of laser modes for such off-angle propagation. In the geometries described, these highly angle-dependent MLD reflectors thereby become a means of mode selection. The zig-zag line **(7)** which depicts the direction of mode propagation is only for demonstration, but indicates that the concentration of allowed modes is at or near normal incidence. The precise angle of the dominant mode will be determined by such design considerations as the [precise angle of incidence desired] (change) the preferred angle-of-incidence, the fluorescence spectra of the gain [media] medium (change), the type of coupling desired, etc.

(change)
laser cavity structure

In the [optical resonator] of the present invention, confinement of the laser modes to paths that are at or near to normal incidence allows several unique coupling configurations. One such configuration is shown in **FIG. 3**, wherein laser radiation is

coupled from the laser[, not through partially reflective mirrors, but] (delete) by introducing the media to be processed into the center of the laser cavity. This may be accomplished through implementation of a tube **(8)**, which separates the gain [media] medium (change) from the process media passing through the tube interior, thereby providing a process volume within the cavity. The latter embodiment will be particularly effective in the processing of media that possess low absorption cross-sections, such as gases and vapors. Alternatively, the [volume] central coupling structure (change) designated by the tube **(8)** may instead contain a cone-shaped optical element for extraction of laser light from the center of the cavity as has been described in numerous papers and patents of the prior art.

The cross-sectional figure of the [resonator] cavity (change) mirror may be designed variously, dependent upon the type of gain [media] (change) medium and lasing action required. In **FIG. 4**, the surface of revolution possesses a cross-sectional figure with a radius of curvature equivalent to that of the surface of revolution as viewed from the top in **FIG. 3**, thereby rendering it a spherical section. In this embodiment, laser emission is confined to propagate through a small volume (17) (insert) located at the center of the spherical mirror, intersected by the axis of circular symmetry **(9)**, thereby allowing an unusually high power density within this small volume.

Another embodiment of the present invention is presented in **FIG. 5**, in which the cross-sectional figure of the surface of revolution– again, identical to the MLD/substrate interface – is straight, thereby rendering the surface of revolution a cylinder. The cylindrical shape of the [resonator] laser cavity structure (change) in the latter embodiment serves to demonstrate an

added utility that is realized with the incorporation of the described MLD's. Unlike the [resonator] cavity (change) geometries of the prior art, linear and other, which use relatively low-finesse reflectors, the present invention allows the stability associated with a particular cavity mirror selection to be increased. Whereas flat (or cylindrical) cavity mirrors will typically support parasitic "walk-off" modes which can decrease the overall Q-factor of the laser cavity, these same modes, such as exemplified by propagation direction **(6)** in **FIG. 5**, will be discouraged due to the low reflectivity of the cavity mirrors at these angles.

In an alternative embodiment of the present invention, laser radiation may also be coupled out of the laser cavity through the edge of the cavity, as in **FIG. 6**. This latter coupling may be accomplished by selectively removing or preventing the MLD deposition – through etching, masking, etc. – so as to provide an effective (insert) aperture **(10)** through which radiation may transmit. Benefits of the invention, as set forth in the embodiments of **FIG. 6**, include the ability to combine a high degree of mode selection with an unusually high cavity Q (and commensurately low threshold). [As such, the divergence of the emitted beam may be more easily controlled than with disk and spherical lasers of the prior art.] (delete)

In **FIG. 7** is another embodiment of the present invention that allows for edge pumping of the circular cavity. [While the] The (change) laser cavities described in the present invention may comprise gas, solid, or liquid gain media, and may be pumped by any of the compatible methods described in the art, such as by a discharge. Also, (insert) the present invention allows for a unique

method of optical pumping. Because of the reflectance and, inversely, the transmission characteristics of the high-finesse MLD's [developed for] of (change) the present invention, lasers of the present invention may easily be pumped with laser radiation which corresponds to the peak absorption region of the gain medium's absorption spectrum. It is possible in the present invention to efficiently couple in the pump radiation through the [resonator] cavity (change) mirror and MLD. In this manner, diode lasers could be positioned around the periphery of the [resonator] cavity (change) mirror.

It should be noted that, in embodiments of the present invention where the laser cavity is fabricated with a disk-like aspect, thermal stability is typically more easily obtained than in other laser cavities. This latter advantage is due to the ability to effectively heat-sink the cavity through its planar sides – as indicated by dashed lines **(18)** in **FIGS. 4-5** – as these surfaces need not be transparent. In fact, these surfaces can possess any of a number of reflecting, absorbing, or scattering characteristics, depending on the application. The ability to heat-sink these cavities can be particularly important in the case that the gain [media] medium (change) is solid state. Heat-sinking, in such a case, (insert) may also be performed effectively through the [resonator] cavity (change) mirror, as long as the outer layers of the [resonator] cavity (change) mirror are specified so as to prevent any possible (insert) TIR of [the] unwanted (change) laser wavelengths. If the [resonator] laser cavity structure (change) of the present invention is to be operated in an ambient medium which possesses a refractive index, n_A, substantially (insert) lower than n_G, then an absorbing and/or scattering layer is preferably utilized externally to the MLD. This latter use of an absorbing and/or scattering layer serves to prevent specular reflection of unwanted cavity emissions back through the MLD to re-

enter the gain volume. Such measures could be implemented in the case that the gain [media] is solid state.
medium (change)

It is not intended that the MLD reflector be restricted to the embodiments of FIG.1, as the latter embodiments are presented primarily for the purpose of teaching the invention. The MLD implemented in a particular embodiment will depend on its particular requirements. The MLD may comprise organic or inorganic materials, or a combination of both. The design of the MLD reflector may vary considerably, as well. For instance, certain layer pairs within the MLD may possess a much higher Δn without
of FIG.2 (insert)
appreciably increasing the FWHM. The thin film materials utilized may possess amorphous or crystalline microstructures; and as such, may be optically isotropic, uniaxial or biaxial, depending upon the precise transmission characteristics of the MLD reflector. The MLD reflector may, in some applications, be designed for peak reflectance at a relatively large angle of incidence. Various other functions may also be incorporated into the MLD design, such as an anti-reflection coating, or the transmission of a particular fluorescence peak.

It should also be noted that the embodiments of **FIGS. 3-4** do not require that the
cavity laser (change)
described spherical [resonator] be restricted to any particular major spherical section. In
cavity structure (change)
fact, the [resonator] sectional view of **FIG. 4** may as easily describe operation of a
cavity (change)
[resonator] that is not truncated at all, so that the [resonator] is a complete sphere. Also, the
cavity structure (change)
MLD described herein may, in many circumstances, be deposited on the external surface of the substrate, therein defining the required surface of revolution. In these latter

cavity interior (change)

circumstances, the substrate would reside within the [resonator volume] and hence would need to be quite transparent to the desired wavelengths. Such a case might be when the required surface of revolution is the external surface of a sphere, which is (insert) composed of a laser glass or crystalline material.

The present invention is seen to have potential applications in several areas. One such application would be in the treatment of optical fibers or optical fiber preforms, where the fiber or preform could be passed through the center of a laser cavity similar to that described in **FIG. 3**. Another potential application could arise in the general field of vapor deposition, where various vapors or gases might be ionized, heated, or otherwise altered by passing through the process volume of **FIG. 3**. [Yet another potential application for the present invention is in the area of micro-optics. For example, microspheres of SiO_2 could be coated with MLD's in accordance with the embodiments of the present invention. These same microspheres could be fabricated with fluorescing components incorporated into the SiO_2 matrix, therein providing a laser structure that might be pumped by various means. Alternatively, the gain material might be a semiconductor, as well; as such, the MLD reflector would allow photoluminescence, or be designed of semiconductor materials that allow cathode luminescence or charge injection of the gain medium.] (delete)

laser cavity (change)

The preceding description provides an [optical resonator] structure that may be operated as a laser, optical amplifier, or other, optically resonating, device. Although the present invention has been described in detail with reference to the embodiments shown in the drawings, it is not intended that the invention be restricted to such embodiments. It

will be apparent to one practiced in the art that various departures from the foregoing description and drawings may be made without departure from the scope or spirit of the invention.

What is claimed is:

1. A structure for providing optically resonant modes, comprising:

   a.) a cavity structure providing a surface of revolution;

   b.) a multilayer dielectric reflector deposited on the surface of revolution, the reflector defining an optically resonant cavity with resonant modes, the reflector substantially delimiting propagation within the cavity to preferred resonant modes;

   c.) an optical gain medium within the optical cavity, the medium disposed for emitting optical radiation into the preferred modes.

2. The structure of Claim 1, wherein the medium is pumped by a discharge.

3. The structure of Claim 1, wherein additional layers are deposited for additional functions.

4. The structure of Claim 1, wherein the multilayer dielectric reflector contains more than 60 layer pairs, the pairs having a refractive index difference, $n_H - n_L < 0.2$.

5. The structure of Claim 1, wherein a material with an optical absorption cut-off limits unwanted propagation in the structure.

6. The structure of Claim 1, wherein the structure also defines a central process space in a central region of the cavity.

7. The structure of Claim 1, wherein a substantially conical reflector is used to reflect the radiation.

8. The structure of Claim 1, wherein the radiation is used for materials processing.

9. The structure of Claim 1, wherein the radiation is used for the treatment of optical fiber.

10. The structure of Claim 1, wherein the radiation is used for the treatment of optical fiber preforms.

11. The structure of Claim 1, wherein the radiation is used for the treatment of semiconductor processing gases.

12. The structure of Claim 1, wherein the gain medium is a gas.

13. The structure of Claim 1, wherein the gain medium is solid state.

14. The structure of Claim 1, wherein the surface of revolution is discontinuous.

15. The structure of Claim 1, wherein the reflector is discontinuous.

16. The structure of Claim 1, wherein the gain medium provides a narrow fluorescence spectrum.

17. The structure of Claim 1, wherein radiation is coupled through the surface of revolution.

18. A structure for providing optically resonant modes, comprising:

a.) a cavity structure providing a spherical surface of revolution;

b.) a multilayer dielectric reflector deposited on the surface, the reflector defining an optically resonant cavity with resonant modes, the reflector having an angle-dependence, so that mode propagation within the cavity is substantially limited to preferred resonant modes; and,

c.) a gain medium within the cavity, the medium disposed for emitting optical radiation into the preferred modes.

19. The structure of Claim 18, wherein the cavity comprises a solid, the solid transmitting a desired optical spectrum.

20. The structure of Claim 18, wherein the gain medium is a gas.

21. A structure providing optically resonant modes, comprising:

a.) a cavity structure providing opposing optically reflecting surfaces, the opposing surfaces defining a cavity;

b.) a multilayer dielectric reflector deposited on at least one opposing surface, the reflector composed of at least one hundred-twenty (120) alternating layers of high index n_H and low index n_L, wherein n_H and n_L are real refractive indices, wherein $n_H - n_L < 0.1$;

c.) an optical gain medium substantially within the optical cavity, the medium disposed for emitting radiation, a solid angle of propagation for the radiation being delimited by the reflector.

ABSTRACT

laser apparatus (change)

A novel [resonator structure] is disclosed which pertains to laser resonator geometries possessing circular symmetry, such as in the case of disk or spherical lasers. The disclosed invention utilizes multi-layer dielectric (MLD) thin film reflectors of

many layer pairs of very small refractive index difference, the MLD deposited on to a surface of revolution, thereby forming an optical cavity (change) (change)

[unusually high-finesse]. These [filters] are disposed in such a way as to allow selection of preferred

dielectric reflectors a (change)

low order modes and suppression of parasitic modes while allowing [an extremely] high

preferred modes (change)

cavity Q factor for [the modes selected]. The invention disclosed, in its preferred embodiments, is seen as particularly useful in applications requiring high efficiency in the production and coupling of coherent radiation. [The invention is also well suited for (delete) achieving mode selection and narrow line-widths.] This is accomplished in a cavity design that is relatively compact and economical.

APPENDIX A.1

McGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS

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anisochela [INV ZOO] A chelate sponge spicule with dissimilar ends. { ¦a,nis·ə'kē·lə }

anisocytosis [MED] A condition in which the erythrocytes show a considerable variation in size due to excessive quantities of hemoglobin. { ¦a,nis·ə,sī'tō·səs }

anisodactylous [VERT ZOO] Having unequal digits, especially referring to birds with three toes forward and one backward. { ¦a,nis·ə'dak·tə·ləs }

anisodesmic [MINERAL] Pertaining to crystals or compounds in which the ionic bonds are unequal in strength. { ¦a,nis·ə'dez·mik }

anisogamete *See* heterogamete. { ¦a,nis·ə'ga ,mēt }

anisogamy *See* heterogamy. { ¦a,nis'äg·ə·mē }

anisole [ORG CHEM] $C_6H_5OCH_3$ A colorless liquid that is soluble in ether and alcohol, insoluble in water; boiling point is 155°C; vapors are highly toxic; used as a solvent and in perfumery. { 'an·ə,sōl }

anisomerous [BOT] Referring to flowers that do not have the same number of parts in each whorl. { ,a,nī'säm·ə·rəs }

anisometric particle [VIROL] Any unsymmetrical, rod-shaped plant virus. { ¦a,nī·sə¦me·trik 'pärd·ə·kəl }

Anisomyaria [INV ZOO] An order of mollusks in the class Bivalvia containing the oysters, scallops, and mussels. { ,a,nī·sə,mī'a·rē·ə }

anisophyllous [BOT] Having leaves of two or more shapes and sizes. { ¦a,nī·sə¦fil·əs }

Anisoptera [INV ZOO] The true dragonflies, a suborder of insects in the order Odonata. { ,a,nī'säp·tə·rə }

anisostemonous [BOT] Referring to a flower whose number of stamens is different from the number of carpels, petals, and sepals. { ¦a,nī·sä'stem·ə·nəs }

Anisotomidae [INV ZOO] An equivalent name for Leiodidae. { ¦a,nī·sə'täm·ə,dē }

anisotropic [PHYS] Showing different properties as to velocity of light transmission, conductivity of heat or electricity, compressibility, and so on, in different directions. Also known as aeolotropic. { ¦a,nī·sə¦träp·ik }

anisotropic magnetoresistance [SOLID STATE] A type of magnetoresistance displayed by all metallic magnetic materials, which arises because conduction electrons have more frequent collisions when they move parallel to the magnetization in the material than when they move perpendicular to it. { ,an·ə·sə¦trō·pik ,mag,ned·ō·ri'sis·təns }

anisotropic membrane [CHEM ENG] An ultrafiltration membrane which has a thin skin at the separating surface and is supported by a spongy sublayer of membrane material. { ¦a,nī·sə¦träp·ik 'mem,brān }

anisotropy [ASTRON] The departure of the cosmic microwave radiation from equal intensity in all directions. [BOT] The property of a plant that assumes a certain position in response to an external stimulus. [PHYS] The characteristic of a substance for which a physical property, such as index of refraction, varies in value with the direction in or along which the measurement is made. Also known as aeolotropy; eolotropy. [ZOO] The property of an egg that has a definite axis or axes. { ¦a,nī'sä·trə·pē }

anisotropy constant [ELECTROMAG] In a ferromagnetic material, temperature-dependent parameters relating the magnetization in various directions to the anisotropy energy. { ¦a,nī'sä·trə·pē ,kän·stənt }

anisotropy energy [ELECTROMAG] Energy stored in a ferromagnetic crystal by virtue of the work done in rotating the magnetization of a domain away from the direction of easy magnetization. { ¦a,nī'sä·trə·pē ,en·ər·jē }

anisotropy factor *See* dissymmetry factor. { ¦a,nī'sä·trə·pē ,fak·tər }

ankaramite [PETR] A mafic olivine basalt primarily composed of pyroxene with smaller amounts of olivine and plagioclase and accessory biotite, apatite, and opaque oxides. { 'aŋ·kə'rä,mīt }

ankaratrite *See* olivine nephelinite. { ,aŋ·kə'rä,trīt }

anker [MECH] A unit of capacity equal to 10 U.S. gallons (37.854 liters); used to measure liquids, especially honey, oil, vinegar, spirits, and wine. { 'aŋ·kər }

ankerite [MINERAL] $Ca(Fe,Mg,Mn)(CO_3)_2$ A white, red, or gray iron-rich carbonate mineral associated with iron ores and found in thin veins in coal seams; specific gravity is 2.95–3.1. Also known as cleat spar. { 'aŋ·kə,rīt }

ankle [ANAT] The joint formed by the articulation of the leg bones with the talus, one of the tarsal bones. { 'aŋ·kəl }

ankle breadth [ANTHRO] The distance measured between projections at lower ends of the tibia and fibula. { 'aŋ·kəl ,bredth }

ankle thickness [ANTHRO] Distance measured perpendicular to ankle breadth. { 'aŋ·kəl ,thik·nəs }

Ankylosauria [PALEON] A suborder of Cretaceous dinosaurs in the reptilian order Ornithischia characterized by short legs and flattened, heavily armored bodies. { ¦aŋ·kə·lə'sòr·ē·ə }

ankylosing spondylitis *See* spondylitis. { 'aŋ·kə,lōz·iŋ ,spän·də'līd·əs }

ankylosis Also spelled anchylosis. [MED] Stiffness or immobilization of a joint due to a surgical or pathologic process. [PHYS] The loss by a system of one or more degrees of freedom through development of one or more frictional constraints. { ,aŋ·kə'lō·səs }

ankyrin [CELL MOL] A protein found in the cell membrane of erythrocytes that attaches the membrane to the cytoskeleton protein spectrin. { aŋ'kī·rən }

ANL *See* automatic noise limiter.

anlage [EMBRYO] Any group of embryonic cells when first identifiable as a future organ or body part. Also known as blastema; primordium. { 'än,läg·ə }

annabergite [MINERAL] $(Ni,Co)_3(AsO_4)_2 \cdot 8H_2O$ A monoclinic mineral usually found as apple-green incrustations as an alteration product of nickel arsenides; it is isomorphous with erythrite. Also known as nickel bloom; nickel ocher. { 'a·nə,bər,gīt }

annatto [BOT] *Bixa orellana.* A tree found in tropical America, characterized by cordate leaves and spinose, seed-filled capsules; a yellowish-red dye obtained from the pulp around the seeds is used as a food coloring. { ə'näd·ō }

anneal [ENG] To treat a metal, alloy, or glass with heat and then cool to remove internal stresses and to make the material less brittle. Also known as temper. [GEN] To recombine complementary strands of deoxyribonucleic acid that were separated by heating or other means of denaturation. { ə'nēl }

annealing furnace [ENG] A furnace for annealing metals or glass. Also known as annealing oven. { ə'nēl·iŋ ,fər·nəs }

annealing oven *See* annealing furnace. { ə'nēl·iŋ ,əv·ən }

annealing point [THERMO] The temperature at which the viscosity of a glass is $10^{13.0}$ poises. Also known as annealing temperature; 13.0 temperature. { ə'nēl·iŋ ,pȯint }

annealing temperature *See* annealing point. { ə'nēl·iŋ ,tem·prə·chər }

annealing twin [MET] A twinned crystal that is formed as molten metal is cooled and solidified. { ə'nēl·iŋ ,twin }

Annedidae [VERT ZOO] A small family of limbless, snakelike, burrowing lizards of the suborder Sauria. { ə'ned·ə,dē }

Annelida [INV ZOO] A diverse phylum comprising the multisegmented wormlike animals. { ə'nel·ə·də }

annex point [MAP] A point used to assist in the relative orientation of vertical and oblique photographs; selected in the overlap area between the vertical and its corresponding oblique photograph, about midway between the pass points. { 'an,eks ,pȯint }

annidation [ECOL] The phenomenon whereby a mutant is maintained in a population because it can flourish in an available ecological niche that the parent organisms cannot utilize. { ,an·ə'dā·shən }

Anniellidae [VERT ZOO] A family of limbless, snakelike lizards in the order Squamata. { ,an·ē'el·ə,dē }

annihilation [PARTIC PHYS] A process in which an antiparticle and a particle combine and release their rest energies in other particles. { ə,nī·ə'lā·shən }

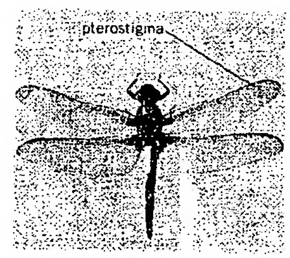
annihilation operator [QUANT MECH] An operator which reduces the occupation number of a single state by unity; for example, an annihilation operator applied to a state of one particle yields the vacuum. Also known as destruction operator. { ə,nī·ə'lā·shən ¦äp·ə,rād·ər }

annihilation radiation [PARTIC PHYS] Electromagnetic radiation arising from the collision, and resulting annihilation, of an electron and a positron, or of any particle and its antiparticle. { ə,nī·ə'lā·shən ,rād·ē'ā·shən }

annihilator [MATH] For a set S, the class of all functions of specified type whose value is zero at each point of S. { ə'nī·ə,lād·ər }

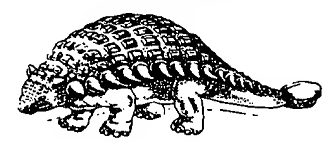
anniversary clock [HOROL] A clock that can run as long as

ANISOPTERA



An adult dragonfly, showing the thickened spot, pterostigma, on the costal margin of the wing.

ANKYLOSAURIA



Restoration of the armored Cretaceous dinosaur *Ankylosaurus* (about 20 feet or 6 meters long).

such as pressure, are not dependent on the direction along which they are measured. { ¦ī·sə¦trä·pik 'plaz·mə }

isotropic radiation [ELECTROMAG] Radiation which is emitted by a source in all directions with equal intensity, or which reaches a location from all directions with equal intensity. { ¦ī·sə¦trä·pik ,rād·ē'ā·shən }

isotropic radiator [PHYS] An energy source that radiates uniformly in all directions. { ¦ī·sə¦trä·pik 'rād·ē,ād·ər }

isotropic turbulence [FL MECH] Turbulence whose properties, especially statistical correlations, do not depend on direction. { ¦ī·sə¦trä·pik 'tər·byə·ləns }

isotropic universe [ASTRON] A universe postulated to have the same properties when viewed from all directions. { ¦ī·sə¦trä·pik 'yü·nə,vərs }

isotropy [PHYS] The quality of a property which does not depend on the direction along which it is measured, or of a medium or entity whose properties do not depend on the direction along which they are measured. { ī'sä·trə·pē }

isotropy group [MATH] For an operation of a group G on a set S, the isotropy group of an element s of S is the set of elements g in G such that $gs = s$. { 'ī·sə,trō·pē ,grüp }

isotypes [IMMUNOL] **1.** A series of antigens, for example, blood types, common to all members of a species but differentiating classes and subclasses within the species. **2.** Different classes of immunoglobulins that have the same antigenic specificity. { 'ī·sə,tīps }

isotypic [CRYSTAL] Pertaining to a crystalline substance whose chemical formula is analogous to, and whose structure is like, that of another specified compound. { ¦ī·sə¦tip·ik }

isovalent conjugation [PHYS CHEM] An arrangement of bonds in a conjugated molecule such that alternative structures with an equal number of bonds can be written; an example occurs in benzene. { ¦ī·sə¦vā·lənt kən'jəŋk·shən }

isovalent hyperconjugation [PHYS CHEM] An arrangement of bonds in a hyperconjugated molecule such that the number of bonds is the same in the two resonance structures but the second structure is energetically less favorable than the first structure; examples are $H_3{\equiv}C{-}C^{+}H_2$ and $H_3{\equiv}C{-}CH_2$. { ¦ī·sə¦vā·lənt ,hī·pər,kän·jə'gā·shən }

isovaleral *See* isovaleraldehyde. { ¦ī·sō¦val·ə·rəl }

isovaleraldehyde [ORG CHEM] $(CH_3)_2CHCH_2CHO$ A colorless liquid with an applelike odor and a boiling point of 92°C; soluble in alcohol and ether; used in perfumes and pharmaceuticals and for flavoring. { ¦ī·sō¦val·ər'al·də,hīd }

isovaleric acid [ORG CHEM] $(CH_3)_2CHCH_2COOH$ Colorless liquid with disagreeable taste and aroma; boils at 176°C; soluble in alcohol and ether; found in valeriana, hop, tobacco, and other plants; used in flavors, perfumes, and medicines. { ¦ī·sō·və'ler·ik 'as·əd }

2-isovaleryl-1,3-indandione [ORG CHEM] $C_{14}H_{14}O_3$ A yellow, crystalline compound with a melting point of 67–68°C; insoluble in water; used as a rodenticide. { ¦tü ¦ī·sō'val·ə,ril ¦wən ¦thrē ,in·dən'dī,ōn }

isovel *See* isotach. { 'ī·sə,vel }

isovolumic *See* isochoric. { ¦ī·sō¦väl·yə·mik }

isozyme *See* isoenzyme. { 'ī·sə,zīm }

ISP *See* imperial smelting process; Internet Service Provider.

i-spin *See* isotopic spin. { 'ī ,spin }

ISR *See* Intersecting Storage Rings.

Israel's theorem [RELAT] A theorem of general relativity essentially proving that the Schwarzschild solution is the unique solution of Einstein's equations describing nonrotating black holes in empty space and that the Reissner-Nordstrom solution is the unique solution describing nonrotating charged black holes. { 'iz·rē·əlz ,thir·əm }

ISS *See* ion scattering spectroscopy.

isthmus [BIOL] A passage or constricted part connecting two parts of an organ. [GEOGR] A narrow strip of land having water on both sides and connecting two large land masses. [MATH] *See* bridge. { 'is·məs }

Istiophoridae [VERT ZOO] The billfishes, a family of oceanic perciform fishes in the suborder Scombroidei. { ,is·tē·ə'fȯr·ə,dē }

ISTS *See* impulsive stimulated thermal scattering.

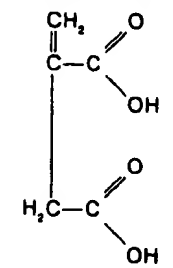
Isuridae [VERT ZOO] The mackerel sharks, a family of pelagic, predacious galeoids distinguished by a heavy body, nearly symmetrical tail, and sharp, awllike teeth. { ī'sür·ə,dē }

itabirite [GEOL] A laminated, metamorphosed, oxide-facies iron formation in which the original chert or jasper bands have been recrystallized into megascopically distinguished grains of quartz and in which the iron is present as thin layers of hematite, magnetite, or martite. { ,ēd·ə'bi,rīt }

itacolumite [PETR] A fine-grained, thin-bedded sandstone or a schistose quartzite that contains mica, chlorite, and talc and that exhibits flexibility when split into slabs. Also known as articulite. { ¦id·ə'käl·ə,mīt }

itaconic acid [ORG CHEM] $CH_2{:}C(COOH)CH_2COOH$ A colorless crystalline compound that decomposes at 165°C, prepared by fermentation with *Aspergillus terreus;* used as an intermediate in organic synthesis and in resins and plasticizers. { ¦id·ə¦kän·ik 'as·əd }

ITACONIC ACID



Structural formula of itaconic acid.

itatartaric acid [ORG CHEM] $C_5H_8O_6$ A compound produced experimentally by fermentation; formed as a minor product, 5.8% of total acidity produced, of an itaconic-acid producing strain of *Aspergillus niger.* { ¦id·ə¦tär·də·rik 'as·əd }

IT calorie *See* calorie. { ¦ī'tē ,kal·ə·rē }

itch [PHYSIO] An irritating cutaneous sensation allied to pain. { ich }

item [COMPUT SCI] A set of adjacent digits, bits, or characters which is treated as a unit and conveys a single unit of information. { 'īd·əm }

item advance [COMPUT SCI] A technique of efficiently grouping records to optimize the overlap of read, write, and compute times. { 'īd·əm əd,vans }

item design [COMPUT SCI] The specification of what fields make up an item, the order in which the fields are to be recorded, and the number of characters to be allocated to each field. { 'īd·əm di,zīn }

item size [COMPUT SCI] The length of an item expressed in characters, words, or blocks. { 'īd·əm ,sīz }

iterated integral [MATH] An integral over an area or volume designated to be performed by successive integrals over line segments. { 'īd·ə,rād·əd 'int·ə·grəl }

iteration *See* iterative method. { ,īd·ə'rā·shən }

iteration process [COMPUT SCI] The process of repeating a sequence of instructions with minor modifications between successive repetitions. { ,īd·ə'rā·shən ,prä·səs }

iterations per second [COMPUT SCI] In computers, the number of approximations per second in iterative division; the number of times an operational cycle can be repeated in 1 second. { ,īd·ə'rā·shənz pər 'sek·ənd }

iterative array [COMPUT SCI] In a computer, an array of a large number of interconnected identical processing modules, used with appropriate driver and control circuits to permit a large number of simultaneous parallel operations. { 'īd·ə,rād·iv ə'rā }

iterative division [COMPUT SCI] In computers, a method of dividing by use of the operations of addition, subtraction, and multiplication; a quotient of specified precision is obtained by a series of successively better approximations. { 'īd·ə,rād·iv di'vizh·ən }

iterative filter [ELECTR] Four-terminal filter that provides iterative impedance. { 'īd·ə,rād·iv 'fil·tər }

iterative impedance [ELECTR] Impedance that, when connected to one pair of terminals of a four-terminal transducer, will cause the same impedance to appear between the other two terminals. { 'īd·ə,rād·iv im'pēd·əns }

iterative method [MATH] Any process of successive approximation used in such problems as numerical solution of algebraic equations, differential equations, or the interpolation of the values of a function. Also known as iteration. { 'īd·ə,rād·iv 'meth·əd }

iterative process [MATH] A process for calculating a desired result by means of a repeated cycle of operations, which comes closer and closer to the desired result; for example, the arithmetical square root of N may be approximated by an iterative process using additions, subtractions, and divisions only. { 'īd·ə,rād·iv 'prä·səs }

iterative routine [COMPUT SCI] A computer program that obtains a result by carrying out a series of operations repetitiously until some specified condition is met. { 'īd·ə,rād·iv rü'tēn }

iteroparity [BIOL] Reproduction that occurs repeatedly over the life of the individual. { ,īd·ə·rə'par·əd·ē }

iteroparous [ZOO] Capable of breeding or reproducing multiple times. { ,īd·ə·rə'par·əs }

Ithomiinae [INV ZOO] The glossy-wings, a subfamily of weak-flying lepidopteran insects having on the wings broad,

R−N=C=S, where R may be an alkyl or aryl group; an example is mustard oil. Also known as sulfocarbimide. { ˌī·sə,thī·ō'sī·ə,nāt }

isotimic [METEOROL] Pertaining to a quantity which has equal value in space at a particular time. { ¦ī·sə¦tim·ik }

isotimic line [METEOROL] On a given reference surface in space, a line connecting points of equal value of some quantity; most of the lines drawn in the analysis of synoptic charts are isotimic lines. { ¦ī·sə¦tim·ik 'līn }

isotimic surface [METEOROL] A surface in space on which the value of a given quantity is everywhere equal; isotimic surfaces are the common reference surfaces for synoptic charts, principally constant-pressure surfaces and constant-height surfaces. { ¦ī·sə¦tim·ik 'sər·fəs }

isotone [NUC PHYS] One of several nuclides having the same number of neutrons in their nuclei but differing in the number of protons. { 'ī·sə,tōn }

isotonic [PHYSIO] **1.** Having uniform tension, as the fibers of a contracted muscle. **2.** Of a solution, having the same osmotic pressure as the fluid phase of a cell or tissue. { ¦ī·sə¦tän·ik }

isotonic sodium chloride solution *See* normal saline. { ¦ī·sə¦tän·ik ¦sōd·ē·əm 'klȯr,īd sə,lü·shən }

isotope [NUC PHYS] One of two or more atoms having the same atomic number but different mass number. { 'ī·sə,tōp }

isotope abundance [NUC PHYS] The ratio of the number of atoms of a particular isotope in a sample of an element to the number of atoms of a specified isotope, or to the total number of atoms of the element. { 'ī·sə,tōp ə¦bən·dəns }

isotope dilution [NUCLEO] The introduction of a radioisotope into stable isotopes of an element in order to make volume, mass, and age measurements of the element. { 'ī·sə,tōp də,lü·shən }

isotope-dilution analysis [ANALY CHEM] Variation on paper-chromatography analysis; a labeled radioisotope of the same type as the one being quantitated is added to the solution, then quantitatively analyzed afterward via radioactivity measurement. { 'ī·sə,tōp də¦lü·shən ə,nal·ə·səs }

isotope effect [PHYS CHEM] The effect of difference of mass between isotopes of the same element on nonnuclear physical and chemical properties, such as the rate of reaction or position of equilibrium, of chemical reactions involving the isotopes. [SOLID STATE] Variation of the transition temperatures of the isotopes of a superconducting element in inverse proportion to the square root of the atomic mass. { 'ī·sə,tōp i,fekt }

isotope exchange [NUCLEO] **1.** Exchange of places by two atoms, but different isotopes, of the same element in two different molecules, or in different locations of the same molecule. **2.** The transfer of isotopically tagged atoms from one chemical form or valence state to another, without net chemical reaction. { 'ī·sə,tōp iks¦chānj }

isotope-exchange reaction [CHEM] A chemical reaction in which interchange of the atoms of a given element between two or more chemical forms of the element occurs, the atoms in one form being isotopically labeled so as to distinguish them from atoms in the other form. { 'ī·sə,tōp iks¦chānj rē,ak·shən }

isotope farm [BOT] A carbon-14 (^{14}C) growth chamber, or greenhouse, arranged as a closed system in which plants can be grown in an atmosphere of carbon dioxide (CO_2) containing ^{14}C and thus become labeled with ^{14}C; isotope farms also can be used with other materials, such as heavy water (D_2O), phosphorus-35 (^{35}P), and so forth, to produce biochemically labeled compounds. { 'ī·sə,tōp ,färm }

isotope fractionation [NUCLEO] Natural or artificial alteration of the isotopic composition of an element via processes of diffusion, evaporation, and chemical exchange, utilizing small differences in physical and chemical properties of isotopes. { 'ī·sə,tōp ,frak·shə¦nā·shən }

isotope lamp [ELECTR] A discharge lamp containing gas of a single isotope and thus producing highly monochromatic light. { 'ī·sə,tōp ,lamp }

isotope separation [NUCLEO] The physical separation of different stable isotopes of an element from one another. { 'ī·sə,tōp ,sep·ə¦rā·shən }

isotope shift [SPECT] A displacement in the spectral lines due to the different isotopes of an element. { 'ī·sə,tōp ,shift }

isotopic age determination *See* radiometric dating. { ¦ī·sə¦täp·ik 'āj di,tər·mə,nā·shən }

isotopic carrier [CHEM] A carrier that differs from the trace it is carrying only in isotopic composition. { ¦ī·sə¦täp·ik 'kar·ē·ər }

isotopic chronometer [NUCLEO] A method of determining the age of geological, archeological, or other samples by measuring the amount of a particular radioisotope and of its daughter isotope in a sample. { ¦ī·sə¦täp·ik krə'näm·əd·ər }

isotopic element [NUC PHYS] An element which has more than one naturally occurring isotope. { ¦ī·sə¦täp·ik 'el·ə·mənt }

isotopic enrichment [NUCLEO] The process by which the relative abundances of the isotopes of a given element are altered in a batch, thus producing a form of the element enriched in a particular isotope. { ¦ī·sə¦täp·ik in'rich·mənt }

isotopic exchange [PHYS CHEM] A process in which two atoms belonging to different isotopes of the same element exchange valency states or locations in the same molecule or different molecules. { ¦ī·sə¦täp·ik iks'chānj }

isotopic incoherence [PHYS] Incoherence in the scattering of neutrons from a crystal lattice due to differences in scattering lengths of different isotopes of the same element. { ¦ī·sə¦täp·ik ,iŋ·kō'hir·əns }

isotopic indicator *See* isotopic tracer. { ¦ī·sə¦täp·ik 'in·də,kād·ər }

isotopic irradiation [NUCLEO] The subjection of a material to radiation from radioactive isotopes for therapeutic or other purposes. { ¦ī·sə¦täp·ik i,rād·ē'ā·shən }

isotopic label *See* isotopic tracer. { ¦ī·sə¦täp·ik 'lā·bəl }

isotopic molecule [NUCLEO] A molecule in which the nucleus of one of the atoms is a special isotope. { ¦ī·sə¦täp·ik 'mäl·ə,kyül }

isotopic number *See* neutron excess. { ¦ī·sə¦täp·ik 'nəm·bər }

isotopic parity *See* G parity. { ¦ī·sə¦täp·ik 'par·əd·ē }

isotopic spin [NUC PHYS] A quantum-mechanical variable, resembling the angular momentum vector in algebraic structure whose third component distinguished between members of groups of elementary particles, such as the nucleons, which apparently behave in the same way with respect to strong nuclear forces, but have different charges. Also known as isobaric spin; isospin; i-spin. { ¦ī·sə¦täp·ik 'spin }

isotopic tracer [CHEM] An isotope of an element, either radioactive or stable, a small amount of which may be incorporated into a sample material (the carrier) in order to follow the course of that element through a chemical, biological, or physical process, and also follow the larger sample. Also known as isotopic indicator; isotopic label; label; tag. { ¦ī·sə¦täp·ik 'trā·sər }

isotron [NUCLEO] A device for sorting isotopes of an element in which ions are accelerated to a fixed energy in a strong electric field, and a radio-frequency field then selects ions according to their velocity, which is inversely proportional to the square root of their mass. { 'ī·sə,trän }

isotropic [BIOL] Having a tendency for equal growth in all directions. [CYTOL] An ovum lacking any predetermined axis. [PHYS] Having identical properties in all directions. { ¦ī·sə¦trä·pik }

isotropic antenna *See* unipole. { ¦ī·sə¦trä·pik an'ten·ə }

isotropic dielectric [ELEC] A dielectric whose polarization always has a direction that is parallel to the applied electric field, and a magnitude which does not depend on the direction of the electric field. { ¦ī·sə¦trä·pik ,dī·ə'lek·trik }

isotropic fabric [PETR] A random orientation in space of the elements that compose a rock. { ¦ī·sə¦trä·pik 'fab·rik }

isotropic fluid [FL MECH] A fluid whose properties are not dependent on the direction along which they are measured. { ¦ī·sə¦trä·pik 'flü·əd }

isotropic flux [PHYS] Radiation, or a flow of particles or matter, which reaches a location from all directions with equal intensity. { ¦ī·sə¦trä·pik 'fləks }

isotropic gain of an antenna *See* absolute gain of an antenna. { ¦ī·sə¦trä·pik 'gān əv ən an'ten·ə }

isotropic material [PHYS] A material whose properties are not dependent on the direction along which they are measured. { ¦ī·sə¦trä·pik mə'tir·ē·əl }

isotropic noise [ELECTROMAG] Random noise radiation which reaches a location from all directions with equal intensity. { ¦ī·sə¦trä·pik 'nȯiz }

isotropic plasma [PL PHYS] A plasma whose properties,

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APPENDIX A.2

Cambridge Dictionary of Science and Technology

General Editor

PETER M. B. WALKER, CBE, FRSE

The right of the University of Cambridge to print and sell all manner of books was granted by Henry VIII in 1534. The University has printed and published continuously since 1584.

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ıt the frame.
late *(Eng.)*. Cast iron plate with the faces ed truly square and having slots on each face for ıg bolts. Used to hold work when marking off on **:e plate** or when machining on a lathe face plate or e tool table.
fter *(Build.)*. See **hip rafter**. The rafter at the hip ɔf to receive the **jack-rafters**. Also *angle ridge*.
ıaft *(Build.)*. An angle bead which is enriched g. a capital base.
ı *(Min.)*. Orthorhombic sulphate of lead, a n lead ore; named after the original locality, y.
ıft *(Build.)*. A strip of wood placed at an angle by plastered surfaces to protect from damage. A l staff is called an *angle bead*.
ıel *(Eng.)*. See **angle iron**.
ıne *(Build.)*. A **quoin**.
pport *(Elec.Eng.)*. A transmission line tower or ced at a point where the line changes its direction. ower or pole differs from a normal tower or pole t has to withstand a force tending to overturn it the resultant pull of the conductors).
(Build.). See **angle brace**.
Textiles). The hair of the angora rabbit or the n and fabric made from it.
ı *(Phys.)*. Unit of wavelength for electromag- liation covering visible light and X-rays. Equal to . The unit is also used for interatomic spacings. Å. Superseded by nanometre ($=10^{-9}$ m). Named : Swedish physicist A.J.Ångström (1814-74).
ırmes *(Zool.)*. Order of Osteichthyes with pelvic girdle absent or reduced; elongate forms. *Eels*.
acceleration *(Phys.)*. The rate of change of velocity; usually expressed in radians per second

acceleration *(Space)*. The acceleration of a ft around an axis, resulting in pitch, roll or yaw.
ontact bearing *(Eng.)*. A ball-bearing for radial ıst loads in which a high shoulder on one side of r race takes the thrust.
liameter *(Astron.)*. Observed diameter of any object expressed as the angle subtended by its · as perceived by the observer.
isplacement *(Phys.)*. The angle turned through y about a given axis, or the angle turned through : joining a moving point to a given fixed point.
listance of stars *(Astron.)*. Observed angular ɔn of two stars as perceived by the observer.
listribution *(Phys.)*. The distribution relative to ent beam of scattered particles or the products of ·eactions.
livergence *(Bot.)*. The angle subtended at the of an apical meristem of a shoot by the mid- : two successive leaf primordia. This varies species but, where the phyllotaxis is spiral it is ly the Fibonacci angle 137.5°.
frequency *(Phys.)*. Frequency of a steady ; phenomenon, expressed in radians per second, ıency in Hz multiplied by 2π. Symbol p or ω; also *·lsatance, radian frequency*.
ıagnification *(Phys.)*. Defined as the ratio of the btended at the eye by an image formed by an ıstrument to the angle subtended by the object at ıed eye.
ıomentum *(Maths.)*. See **momentum**.
ıomentum *(Phys.)*. The moment of the linear ım of a particle about an axis. Any rotating an angular momentum about its centre of mass, *ıngular momentum*. The angular momentum of : of mass of a body relative to an external axis is *ıl angular momentum*. In atomic physics, the ngular momentum of an electron is *quantized* ɔnly have values which are exact multiples of the

angular thread *(Eng.)*. See **vee thread**.
angular velocity *(Phys.)*. The rate of change of angular displacement, usually expressed in radians per second.
Angus-Smith process *(Build.)*. An anticorrosion process applied to sanitary ironwork; this is heated to about 316°C immediately after casting, and then plunged into a solution of 4 parts coal-tar or pitch, 3 parts prepared oil, and 1 part paranaphthalene heated to about 149°C. See **Bower-Barff process**.
anharmonic *(Electronics)*. Said of any oscillation system in which the restoring force is nonlinear with displacement, so that the motion is not simple harmonic.
anharmonic ratio *(Maths.)*. See **cross-ratio**.
anhedral *(Aero.)*. See **dihedral angle**.
anhedral *(Geol.)*. A term used in petrography to denote a crystal which does not show any crystal faces, i.e. one which is irregular in shape.
anhidrosis *(Med.)*. Absence of secretion of sweat.
anhidrosis *(Vet.)*. *Nonsweating, drysweating*. An affection of horses in humid tropical countries characterized by inability to sweat after exercise; believed to be due to prolonged overstimulation of the sweat glands by adrenaline.
anhydrides *(Chem.)*. Substances, including organic compounds and inorganic oxides, which either combine with water to form acids, or which may be obtained from the latter by the elimination of water.
anhydrite *(Build.,Min.)*. Naturally occurring anhydrous calcium sulphate which readily forms gypsum and from which anhydrite plaster is made by grinding to powder with a suitable accelerator.
anhydrite process *(Chem.Eng.)*. A process for the manufacture of sulphuric acid from anhydrite $CaSO_4$. The mineral is roasted with a reducing agent and certain other minerals in large kilns, so that SO_2 gas in relatively low concentration is recovered and after cleaning is passed to a specially designed **contact process**. The solid residue is, under normal conditions, readily converted into cement and this forms an economic factor in the process. In Britain the process has a special significance as it provides a large potential of sulphuric acid from an indigenous source of sulphur.
anhydrous *(Chem.)*. A term applied to oxides, salts etc. to emphasize that they do not contain water of crystallization or water of combination.
anhydrous lime *(Build.)*. See **lime**.
anilides *(Chem.)*. *N-phenyl amides*. A group of compounds in which the hydrogen of the amino group in aniline is substituted by organic acid radicals. The most important compound of this class is *acetanilide*.
aniline *(Chem.)*. $C_6H_5NH_2$, *phenylamine, aminobenzene*, a colourless oily liquid, mp −8°C, bp 189°C, rel.d. 1.024, slightly soluble in water; manufactured by reducing nitrobenzene with iron shavings and hydrochloric acid at 100°C. Basis for the manufacture of dyestuffs, pharmaceuticals, plastic (with methanal) and many other products.
aniline black *(Chem.)*. An azine dye, produced by the oxidation of aniline on the fabric.
aniline dyes *(Chem.)*. A general term for all synthetic dyes having aniline as their base.
aniline foils *(Print.)*. Blocking foils which contain dyestuff; used chiefly for leather.
aniline formaldehyde (methanal) *(Chem.)*. Synthetic resin formed by the polycondensation of aniline with formaldehyde.
aniline oil *(Chem.)*. A coal-tar fraction consisting chiefly of crude aniline.
aniline printing *(Print.)*. See **flexographic printing**.
anilinium chloride *(Chem.)*. *Phenylammonium chloride*, $C_6H_5NH_2.HCl$, mp 198°C, bp 245°C, rel.d. 1.22, white crystals, soluble in most organic solvents and water.
anima, animus *(Behav.)*. Term used in Jungian psychology to denote the unconscious feminine component in

etc.
animal electricity *(Zool.)*. A term used to denote the ability possessed by certain animals (e.g. electric eel) of giving powerful electric shocks.
animal field *(Zool.)*. In developing blastulae, a region distinguished by the character of the contained yolk granules, and representing the first rudiment of the germ band.
animal pole *(Zool.)*. In the developing ovum, the apex of the upper hemisphere, which contains little or no yolk; in the blastula, the corresponding region, wherein the micromeres lie.
animal-sized *(Paper)*. Paper which has been sized by passing the sheet or web through a bath containing a solution essentially of gelatine and then drying. See **tub sizing**.
animation *(Image Tech.)*. Apparent movement produced by recording step-by-step a series of still drawings, three-dimensional objects or computer-generated images.
animism *(Behav.)*. Attributing feelings and intentions to non-living things. In Piagetian theory children's thinking is characterised by animism in the years two to six.
anion *(Phys.)*. Negative ion, i.e. atom or molecule which has gained one or more electrons in an electrolyte, and is therefore attracted to an anode, the positive electrode. Anions include all nonmetallic ions, acid radicals, and the hydroxyl ion. In a primary cell, the deposition of anions on an electrode makes it the negative pole. Anions also exist in gaseous discharge.
anisaldehyde *(Chem.)*. *4-methoxybenzaldehyde*. Colourless liquid; bp 248°C, occurring in aniseed, and used in perfumery.
anisidines *(Chem.)*. *Amino-anisoles, methoxyanilines*, $CH_3O.C_6H_4.NH_2$, bases similar to aniline. Intermediates for dyestuffs.
aniso- *(Genrl.)*. Prefix from Gk. *an*, not; *isos*, equal.
anisocercal *(Zool.)*. Having the lobes of the tail-fin unequal.
anisodactylous *(Zool.)*. Of Birds, having 3 toes turned forward and 1 turned backward when perching, as in the Passeriformes.
anisodesmic structure *(Crystal.)*. One giving a crystal marked difference between its bond strengths in the intersecting axial planes.
anisogamete *(Biol.)*. A gamete differing from the other conjugant in form or size. adj. *anisogamous*.
anisogamy *(Biol.)*. Sexual fusion of gametes that differ in size but not necessarily in form. See **heterogamy, isogamy, oögamy**.
anisokont *(Bot.)*. Having 2 flagella unequal in length but otherwise more or less similar. Cf. **isokont, heterokont**.
anisole *(Chem.)*. *Phenyl methyl ether*, $C_6H_5.O.CH_3$, a colourless liquid, bp 155°C.
anisomeric *(Chem.)*. Not isomeric.
anisopleural *(Zool.)*. Bilaterally asymmetrical.
anisotonic *(Chem.)*. Not isotonic.
anisotropic *(Min.,Phys.)*. Said of crystalline material for which physical properties depend upon direction relative to crystal axes. These properties normally include elasticity, conductivity, permittivity, permeability etc.
anisotropic *(Zool.)*. Of ova, having a definite polarity, in relation to the primary axis passing from the animal pole to the vegetable pole. n. *anisotropy*.
anisotropic conductivity *(Phys.)*. Body which has a different conductivity for different directions of current flow, electric or thermal.
anisotropic dielectric *(Phys.)*. One in which electric effects depend on the direction of the applied field, as in many crystals.
anisotropic liquids *(Chem.)*. See **liquid crystals**.
anisotropy *(Chem.)*. Describes a property of a substance when that property depends on direction as revealed by measurement, e.g. **crystals** and **liquid crystals** in which the refractive index is different in different directions.

and thoracic rigidity.
ankylosis *(Med.)*. Fixation of a joint by fibrous bands within it, or by pathological union of the bones forming the joint.
ankylosis, anchylosis *(Zool.)*. The fusion of two or more skeletal parts, especially bones.
ankylostomiasis *(Med.)*. *Hookworm disease*; infection by two parasitic nematode worms in the small intestine (*Ankylostoma duodenale* and *A. americanum*), which produces iron deficiency for those on an inadequate diet.
anlage *(Zool.)*. See **primordium**.
annabergite *(Min.)*. Hydrated nickel arsenate, apple-green monoclinic crystals, rare, usually massive. Associated with other ores of nickel. Also called *nickel bloom*.
anneal *(Biol.)*. To reform the duplex structure of a nucleic acid.
annealing *(Phys.)*. Process of maintaining a material at a known elevated temperature to reduce dislocations, vacancies and other metastable conditions, e.g. steel or glass. In ferrous alloys the metal is held at a temperature above the upper critical temperature for a variable time and then cooled at a predetermined rate, depending on the alloy and the particular properties of hardness, machineability etc. which are needed. The term is usually qualified, e.g. *quench annealing, isothermal annealing, graphitizing*.
annealing furnace *(Eng.)*. Batch-worked or continuous oven or furnace with controllable atmosphere in which metal, alloy or glass is annealed.
Annelida *(Zool.)*. A phylum of metameric Metazoa, in which the perivisceral cavity is coelomic, and there is only one somite in front of the mouth; typically there is a definite cuticle and chitinous setae arising from pits of the skin; the central nervous system consists of a pair of preoral ganglia connected by commissures to a postoral ventral ganglionated chain; if a larva occurs it is a trochophore. Earthworms, Ragworms, Leeches.
annihilation *(Phys.)*. Spontaneous conversion of a particle and its antiparticle into radiation, e.g. positron and electron yielding two γ-ray photons each of energy 0.511 MeV.
annihilation radiation *(Phys.)*. The radiation produced by the annihilation of an elementary particle with its corresponding antiparticle.
annihilator *(Maths.)*. *An* annihilator of x is y such that $yx = 0$. Here x and y may be elements of rings, functions etc. and need not be the same type of object so long as xy is defined. An annihilator of a set X is y which is an annihilator of every element of X. *The* annihilator is the set of all such individual annihilators.
annite *(Min.)*. The ferrous iron end-member of the biotite series of micas.
annoyance *(Acous.)*. The psychological effect arising from excessive noise. There is no absolute measure, but the annoyance caused by specified classes of noise can be correlated.
annual *(Bot.)*. A plant that flowers and dies within a period of one year from germination. Cf. **ephemeral, biennial, perennial**.
annual equation *(Astron.)*. One of four terms describing the orbit of the Moon, which arises from the eccentricity of the Earth's orbit round the Sun. Its period is one year.
annual load factor *(Elec.Eng.)*. The load factor of a generating station, supply-undertaking, or consumer, taken over a whole year.
annual parallax *(Astron.)*. The motion of the Earth round the Sun causes minute changes in the apparent positions of the stars. The regular annual displacement is the *annual parallax*. It is largest, at 0.71 seconds of arc, for the star **Proxima Centauri**.
annual ring *(Bot.)*. A **growth ring** formed over a year.
annular bit *(Build.)*. A bit which cuts an annular (ring-shaped) channel and leaves intact a central cylindrical plug.

places recording the same intensity of earthquake shocks. See **earthquake**.

ISO sizes *(Paper)*. A series of trimmed, international, metric paper sizes based on a width to length ratio of 1:1.414. The next smaller size in the series is produced by halving the longer dimension e.g. AO is 841 × 1189 mm, A1, 594 × 841 mm, A2, 420 × 594 mm etc. The range includes the A, B and C series of sizes.

isosorbide *(Med.)*. Long-acting nitrate vasodilator used in the treatment and prophylaxis of angina pectoris. Available as its dinitrate or its active metabolite, mononitrate.

isospin *(Phys.)*. Contraction of **isotopic spin**.

isostasy *(Geol.)*. The process whereby areas of crust tend to float in conditions of near equilibrium on the plastic mantle.

isostemonous *(Bot.)*. With stamens in one whorl and equal in number to petals.

isostere *(Meteor.)*. A line on a chart joining points of equal atmospheric **specific volume**.

isosteric *(Chem.)*. Consisting of molecules of similar size and shape.

isotach *(Meteor.)*. A line on a chart joining points of equal wind speed.

isotactic *(Plastics)*. Term denoting linear-substituted hydrocarbon polymers in which the substituent groups all lie on the same side of the carbon chain. See also **atactic** and **syndiotactic**.

isotaxy *(Chem.)*. Polymerization in which the monomers show stereochemical regularity of structure. adj. *isotactic*. Cf. **syndyotaxy**.

isoteniscope *(Chem.)*. An instrument for the static measurement of vapour pressure by observing the change of level of a liquid in a U-tube.

isotherm *(Meteor.)*. A line drawn on a chart joining points of equal temperature.

isothermal *(Phys.)*. (1) Occurring at constant temperature. (2) A curve relating quantities measured at constant temperature.

isothermal change *(Phys.)*. A change in the volume and pressure of a substance which takes place at constant temperature. For gases, Boyle's law applies to isothermal changes.

isothermal efficiency *(Eng.)*. Of a compressor, the ratio of the work required to compress a gas isothermally to the work actually done by the compressor.

isothermal lines, curves *(Phys.)*. Curves obtained by plotting pressure against volume for a gas kept at constant temperature. For a gas sufficiently above its critical temperature for Boyle's law to be obeyed, such curves are rectangular hyperbolas.

isothermal process *(Eng.)*. A physical process, particularly one involving the compression and expansion of a gas, which takes place without temperature change.

isothermal transformation *(Eng.)*. Change in phase which occurs in a metal or alloy at constant temperature after cooling or heating through the equilibrium temperature.

isotones *(Phys.)*. Nuclei with the same neutron number but different atomic numbers (i.e., those lying in a vertical column of a *Segrè chart*).

isotonic *(Biol.)*. See **iso-osmotic**.

isotonic *(Chem.)*. Having the same osmotic pressure, e.g. as that of blood, or of the sap of cells which are being tested for their osmotic properties.

isotonic contraction *(Zool.)*. The type of contraction involved when a muscle shortens while maintaining a constant tension.

isotope *(Phys.)*. One of a set of chemically identical species of atom which have the same **atomic number** but different **mass numbers**. A few elements have only one natural isotope, but all elements have artificially produced radio-isotopes. (Gk. *isos*, same; *topos*, place).

isotope geology *(Geol.)*. The study of the relative abundances of radioactive and stable isotopes in rocks to determine radiometric ages and conditions of formation.

isotope separation *(Phys.)*. Process of altering the spectograph, or may give slight enrichment only as in each stage of a diffusion plant.

isotope structure *(Phys.)*. Hyperfine structure of spectrum lines resulting from mixture of isotopes in source material. The wavelength difference is termed the *isotope shift*.

isotope therapy *(Radiol.)*. Radiotherapy by means of radioisotopes.

isotopic abundance *(Phys.)*. See **abundance ratio**.

isotopic dilution *(Radiol.)*. The mixing of a particular nuclide with one or more of its isotopes.

isotopic dilution analysis *(Phys.)*. A method of determining the amount of an element in a specimen by observing the change in isotopic composition produced by the addition of a known amount of radioactive allobar.

isotopic number *(Phys.)*. See **neutron excess**.

isotopic spin *(Phys.)*. Also called *isobaric spin, isospin, i-spin*. A quantum number assigned to members of a group of elementary particles differing only in electric charge; the particle groups are known as *multiplets*. Thus it is convenient to regard protons and neutrons as two manifestations of the nucleon, with isotopic spin either parallel or anti-parallel to some preferred direction, i.e. they have isotopic spin $+\frac{1}{2}$ and $-\frac{1}{2}$. The nucleon is then a doublet. This can be extended to all baryons and mesons. For example, the triplet π-meson consists of three pions. The small mass differences between the members of a multiplet is associated with their differing charges. The number of members of a multiplet set is $2I + 1$ where I is the isotopic spin, 0 for a singlet, $\frac{1}{2}$ for a doublet, 1 for a triplet, etc. The justification for the classification of particles is that all the members of a multiplet respond identically to strong nuclear interactions, the charges affecting only electromagnetic interactions. Isotopic spin is conserved in all strong interactions and never changes by more than one in a weak interaction. This classification is introduced by *analogy* with the spin or intrinsic angular momentum of atomic spectroscopy; isotopic spin has nothing to do with the nuclear spin of the particles.

isotopic symbols *(Chem.)*. Numerals attached to the symbol for a chemical element, with the following meanings; *upper left*, mass number of atom; *lower left*, nuclear charge of atom; *lower right*, number of atoms in molecule, e.g. ${}_1^2H_2$, ${}_{12}^{24}Mg$.

isotron *(Phys.)*. A device for the separation of isotopes. Pulses from a source of ions are synchronized with a deflecting field. The ions undergo deflections according to their mass.

isotropic *(Phys.)*. Said of a medium, the physical properties of which, e.g., magnetic susceptibility or elastic constants, do not vary with direction.

isotropic dielectric *(Elec.Eng.)*. One in which the electrical properties are independent of the direction of the applied electric field.

isotropic radiator *(Telecomm.)*. An idealised antenna which sends out energy equally in all directions; virtually impossible to realise in practice. Cf. **omnidirectional antenna**.

isotropic source *(Electronics)*. Theoretical source which radiates all its electromagnetic energy equally in all directions.

isozyme *(Biol.)*. *Isoenzyme*. Electrophoretically distinct forms of an enzyme with identical activities, usually coded by different genes.

ISRO *(Space)*. Abbrev. for *Indian Space Research Organisation*, which oversees all Indian space activities.

isthmus *(Zool.)*. A neck connecting two expanded portions of an organ; as the constriction connecting the mid-brain and the hind-brain of Vertebrates.

IT *(Comp.)*. See **information technology**.

itacolumite *(Geol.)*. A micaceous sandstone with loosely-interlocking grains, which enable the rock to bend when cut into thin slabs.

Italian asbestos *(Min.)*. A name often given to tremolite asbestos to distinguish it from Canadian or chrysotile

hook-out blind but having the side arms attached to the blind and capable of sliding up and down on side rods. Also called a **canalette blind**.

Italian roof *(Arch.)*. See **hipped roof**.

italic, italics *(Print.)*. A sloping style of type, thus *italic*.

itchy leg *(Vet.)*. See **chorioptic mange**.

iter *(Zool.)*. A canal or duct, as the reduced ventricle of the mid-brain in higher Vertebrates.

iterated fission expectation *(Phys.)*. Limiting value, after a long time, of the number of fissions per generation in the chain reaction initiated by a specified neutron to which this term applies.

iteration *(Comp.)*. To obtain a result by repeatedly performing the same sequence of steps until a specified condition is satisfied. See **loop**.

iterative impedance *(Phys.)*. The **input impedance** of a four-terminal network or transducer when the output is terminated with the same impedance, or when an infinite series of identical such networks are cascaded. See **image impedance**.

iteroparous *(Zool.)*. Reproducing on two or more occasions during a lifetime.

ITM *(Ships)*. Abbrev. for *Inch Trim Moment*. Same as *moment to change trim one inch*.

ITU *(Telecomm.)*. Abbrev. for *International Telecommunications Union*.

IUPAC *(Chem.)*. Abbrev. for the *Internationa Pure and Applied Chemistry*, a body responsil other things, for the standardization of chemi clature, which it alters frequently.

ivory *(Zool.)*. The dentine of teeth, especially dentine composing the tusks of elephants.

ivory board *(Paper)*. Genuine ivory board is fo high-quality papers by starch-pasting two together.

ivorywood *(For.)*. Rare Australian hardw *Siphonadendron*, prized for engraving, turne frames, inlaying etc.

IVP, IVU *(Med.)*. Abbrev. for *IntraVenous P IntraVenous Urography*, i.e. the demonstratio of the renal tract after the intravenous inje radio-opaque contrast medium.

IW *(Chem.)*. An abbrev. for *Isotopic Weight*.

IX *(Chem.,Min.Ext.)*. Abbrev. for *Ion eXchang*

Izod test *(Eng.)*. A notched-bar impact test i notched specimen held in a vice is struck in th striker carried on a pendulum; the energy al fracture is then calculated from the height to pendulum rises as it continues its swing.

Izod value *(Eng.)*. The energy absorbed in fr standard specimen in an Izod pendulum imp machine.

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Abbreviations
ABC of Music
Accounting
Archaeology*
Architecture*
Art and Artists
Art Terms*
Astronomy
Bible
Biology
British Women Writers
Buddhism*
Business
Card Games
Chemistry
Christian Church
Classical Literature
Classical Mythology*
Colour Medical Dictionary
Colour Science Dictionary
Computing
Dance*
Dates
Earth Sciences
Ecology
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English Folklore*
English Grammar
English Language
English Literature
English Place-Names
Euphemisms
Film*
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First Names
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Geography
Handbook of the World*
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Kings and Queens*
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Scientists
Shakespeare
Ships and the Sea
Sociology
Statistics*
Superstitions
Theatre
Twentieth-Century Art
Twentieth-Century Poetry
Twentieth-Century World History
Weather Facts
Who's Who in Opera*
Who's Who in the Twentieth Century
Word Games
World Mythology
World Religions*
Writers' Dictionary
Zoology

* *forthcoming*

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SCIENCE REF

A Dictionary of Science

APPENDIX A.3

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angular magnificati n (magnifying power) *See* **magnification.**

angular momentum Symbol L. The product of the angular velocity of a body and its *moment of inertia about the axis of rotation, i.e. $L = I\omega$.

anharmonic oscillator An oscillating system (in either *classical physics or *quantum mechanics) that is not oscillating in *simple harmonic motion. In general, the problem of an anharmonic oscillator is not exactly soluble, although many systems approximate to harmonic oscillators and for such systems the *anharmonicity* (the deviation of the system from being a *harmonic oscillator) can be calculated using *perturbation theory. If the anharmonicity is large other approximate or numerical techniques have to be used to solve the problem.

anhydride A compound that produces a given compound on reaction with water. For instance, sulphur trioxide is the (acid) anhydride of sulphuric acid

$$SO_3 + H_2O \rightarrow H_2SO_4$$

See also **acid anhydrides.**

anhydrite An important rock-forming anhydrous mineral form of calcium sulphate, $CaSO_4$. It is chemically similar to *gypsum but is harder and heavier and crystallizes in the rhombic form (gypsum is monoclinic). Under natural conditions anhydrite slowly hydrates to form gypsum. It occurs chiefly in white and greyish granular masses and is often found in the caprock of certain salt domes. It is used as a raw material in the chemical industry and in the manufacture of cement and fertilizers.

anhydrous Denoting a chemical compound lacking water: applied particularly to salts lacking their water of crystallization.

aniline *See* **phenylamine.**

anilinium ion The ion $C_6H_5NH_3^+$, derived from *phenylamine.

animal Any member of the kingdom Animalia, which comprises multicellular organisms that develop from embryos formed by the fusion of haploid eggs and sperm. Unable to manufacture their own food, they feed on other organisms or organic matter (holozoic nutrition; *see* **heterotrophic nutrition**). Animals are therefore typically mobile (to search for food) and have evolved specialized sense organs for detecting changes in the environment; a *nervous system coordinates information received by the sense organs and enables rapid responses to environmental stimuli. Animal *cells lack the cellulose cells walls of *plant cells. For a classification of the animal kingdom, see Appendix.

animal behaviour The activities that constitute an animal's response to its external environment. Certain categories of behaviour are seen in all animals (e.g. feeding, reproduction) but these activities involve different movements in different species and develop in different ways. Some movements are highly characteristic of a species (*see* **instinct**) whereas others are more variable and depend on the interaction between innate tendencies and *learning during the individual's lifetime. Physiologists study how changes in the body (e.g. hormone levels) affect behaviour, psychologists study the mechanisms of learning, and ethologists study the behaviour of the whole animal: how this develops during the individual's lifetime and how it evolved through natural selection (*see* **ethology**).

animal charcoal *See* **charcoal.**

animal starch *See* **glycogen.**

anion A negatively charged *ion, i.e. an ion that is attracted to the *anode in *electrolysis. *Compare* **cation.**

anionic detergent *See* **detergent.**

anionic resin *See* **ion exchange.**

anisogamy Sexual reproduction involving the fusion of gametes that differ in size and sometimes also in form. *See also* **oogamy.** *Compare* **isogamy.**

anisotropic Denoting a medium in which certain physical properties are different in different directions. Wood, for instance, is an anisotropic material: its strength along the grain differs from that perpendicular to the grain. Single crystals that are not cubic are anisotropic with respect to some physical properties, such as the transmission of electromagnetic radiation. *Compare* **isotropic.**

annealing A form of heat treatment applied to a metal to soften it, relieve internal stresses and instabilities, and make it easier to work or machine. It consists of heating the metal to a specified temperature for a specified time, both of which depend on the metal involved, and then allowing it to cool slowly. It is applied to both ferrous and nonferrous metals and a similar process can be applied to other materials, such as glass.

Annelida A phylum of invertebrates comprising the segmented worms (e.g. the earthworm). Annelids have cylindrical soft bodies showing *metameric segmentation, obvious externally as a series of rings separating the segments. Each segment is internally separated from the next by a membrane and bears stiff bristles (*see* **chaeta**). Between the gut and other body organs there is a fluid-filled cavity called the *coelom, which acts as a hydrostatic skeleton. Movement is by alternate contraction of circular and longitudinal muscles in the body wall. The phylum contains three classes: *Polychaeta, *Oligochaeta, and *Hirudinea.

annihilation The destruction of a particle and its *antiparticle as a result of a collision between them. The *annihilation radiation* produced is carried away by *photons or *mesons. For example, in a collision between an electron and a positron the energy produced is carried away by two photons, each having an energy of 0.511 MeV, which is equivalent to the rest-mass energies of the annihilated particles plus their kinetic energies. When nucleons annihilate each other the energy is carried away by mesons.

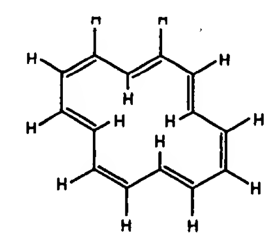
annual A plant that completes its life cycle in one year, during which time it germinates, flowers, produces seeds, and dies. Examples are the sunflower and marigold. *Compare* **biennial; ephemeral; perennial.**

annual rhythm The occurrence of a process or a function in a living organism on a yearly basis. Events that display an annual rhythm can include life cycles, such as those of *annual plants; mating behaviour; some kinds of movement, such as *migration; or growth patterns, such as the *growth rings of woody plant stems. *See also* **biorhythm.**

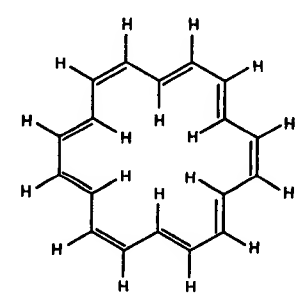
annual ring *See* **growth ring.**

annular parallax Symbol π. The *parallax of a celestial object resulting from the movement of the earth in its orbit during a year. It is equal to the semi major axis of the parallatic ellipse described by the apparent movement of the object against the background of distant stars. Annular parallax (in arc-seconds) is also approximately equal to the reciprocal of the distance to the object (in parsecs).

annulenes Organic hydrocarbons that have molecules containing simple single rings of carbon atoms linked by alternating single and double bonds. Such compounds have even numbers of carbon atoms. Cyclooctatetraene, C_8H_8, is the next in the series following benzene. Higher annulenes are usually referred to by the number of carbon atoms in the ring, as in [10]-annulene, $C_{10}H_{10}$, [12]-annulene, $C_{12}H_{12}$, etc. The lower members are



[14]-Annulene



[18]-Annulene

Annulenes

joining points or places of equal temperature. **2.** A curve on a graph representing readings taken at constant temperature (e.g. the relationship between the pressure and volume of a gas at constant temperature).

isothermal process Any process that takes place at constant temperature. In such a process heat is, if necessary, supplied or removed from the system at just the right rate to maintain constant temperature. *Compare* **adiabatic process.**

isotone One of two or more nuclides that contain the same number of neutrons but different numbers of protons. The naturally occurring isotones, for example, strontium–88 and yttrium–89 (both with 50 neutrons), give an indication of the stability of certain nuclear configurations.

isotonic Describing solutions that have the same osmotic pressure.

isotope One of two or more atoms of the same element that have the same number of protons in their nucleus but different numbers of neutrons. Hydrogen (1 proton, no neutrons), deuterium (1 proton, 1 neutron), and tritium (1 proton, 2 neutrons) are isotopes of hydrogen. Most elements in nature consist of a mixture of isotopes. *See* **isotope separation.**

is t pe separation The separation of the *isotopes of an element from each other on the basis of slight differences in their physical properties. For laboratory quantities the most suitable device is often the mass spectrometer. On a larger scale the methods used include gaseous diffusion (widely used for separating isotopes of uranium in the form of the gas uranium hexafluoride), distillation (formerly used to produce heavy water), electrolysis (requiring cheap electrical power), thermal diffusion (formerly used to separate uranium isotopes, but now considered uneconomic), centrifuging, and laser methods (involving the excitation of one isotope and its subsequent separation by electromagnetic means).

isotopic number (neutron excess) The difference between the number of neutrons in an isotope and the number of protons.

isotopic spin (isospin; isobaric spin) A quantum number applied to hadrons (*see* **elementary particles**) to distinguish between members of a set of particles that differ in their electromagnetic properties but are otherwise apparently identical. For example if electromagnetic interactions and weak interactions are ignored, the proton cannot be distinguished from the neutron in their strong interactions: isotopic spin was introduced to make a distinction between them. The use of the word 'spin' implies only an analogy to angular momentum, to which isotopic spin has a formal resemblance.

isotropic Denoting a medium whose physical properties are independent of direction. *Compare* **anisotropic.**

isozyme (isoenzyme) One of several forms of an enzyme in an individual or population that catalyse the same reaction but differ from each other in such properties as substrate affinity and maximum rates of enzyme–substrate reaction (*see* **Michaelis–Menten curve**).

IT (information technology) The use of computers and telecommunications equipment (with their associated microelectronics) to send, receive, store and manipulate data. The data may be textual, numerical, audio or video, or any combination of these. *See also* **World Wide Web.**

iteration The process of successive approximations used as a technique for solving a mathematical problem. The technique can be used manually but is widely used by computers.

J

Jacob–Monod hypothesis The theory postulated by the French biologists François Jacob (1920–) and Jacques Monod (1910–76) in 1961 to explain the control of *gene expression in bacteria (*see* **operon**). Jacob and Monod investigated the expression of the gene that codes for the enzyme β-galactosidase, which breaks down lactose; the operon that regulates lactose metabolism is called the *lac operon.

jade A hard semiprecious stone consisting either of jadeite or nephrite. *Jadeite*, the most valued of the two, is a sodium aluminium pyroxene, $NaAlSi_2O_6$. It is prized for its intense translucent green colour but white, green and white, brown, and orange varieties also occur. The only important source of jadeite is in the Mogaung region of upper Burma. *Nephrite* is one of the amphibole group of rock-forming minerals. It occurs in a variety of colours, including green, yellow, white, and black. Important sources include Siberia, Turkistan, New Zealand, Alaska, China, and W USA.

jadeite *See* **jade.**

Jahn–Teller effect If a likely structure of a nonlinear molecule or ion would have degenerate orbitals (i.e. two molecular orbitals with the same energy levels) the actual structure of the molecule or ion is distorted so as to split the energy levels ('raise' the degeneracy). The effect is observed in inorganic complexes. For example, the ion $[Cu(H_2O)_6]^{2+}$ is octahedral and the six ligands might be expected to occupy equidistant positions at the corners of a regular octahedron. In fact, the octahedron is distorted, with four ligands in a square and two opposite ligands further away. If the 'original' structure has a centre of symmetry, the distorted structure must also have a centre of symmetry. The effect was predicted theoretically by H. A. Jahn and Edward Teller in 1937.

jasper An impure variety of *chalcedony. It is associated with iron ores and as a result contains iron oxide impurities that give the mineral its characteristic red or reddish-brown colour. Jasper is used as a gemstone.

jaw The part of the vertebrate skeleton that provides a support for the mouth and holds the teeth. It consists of two bones, the upper jaw (maxilla) and the lower jaw (mandible). Members of the Agnatha lack jaws.

jejunum The portion of the mammalian *small intestine that follows the *duodenum and precedes the *ileum. The surface area of the lining of the jejunum is greatly increased by numerous small outgrowths (*see* **villus**). This facilitates the absorption of digested material, which is the prime function of the jejunum.

jellyfish *See* **Cnidaria.**

Jenner, Edward (1749–1823) British physician, who is best known for introducing smallpox vaccination to Britain in 1796 (announced two years later), using a vaccine made from cowpox.

jet A variety of *coal that can be cut and polished and is used for jewellery, ornaments, etc.

jet propulsion (reaction propulsion) The propulsion of a body by means of a force produced by discharging a fluid in the form of a jet. The backward-moving jet of fluid reacts on the body in which it was produced, in accordance with Newton's third law of motion, to create a reactive force that drives the body forward. Jet propulsion occurs in nature, the squid using a form of it to propel itself through water. Although jet-propelled boats and cars have been developed, the main use of jet propulsion is in aircraft and spacecraft. Jet propulsion is the only known method of propulsion in space. In the atmosphere, jet propulsion becomes more efficient at higher altitudes, as efficiency is inversely proportional to the density of the medium through which a body is flying. The three

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NEW CLAIM

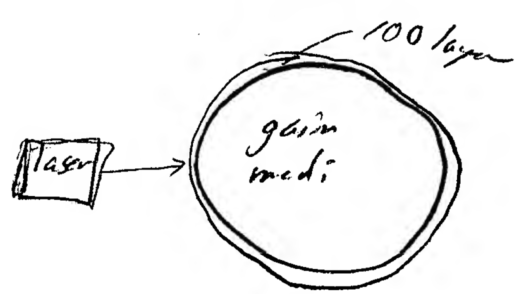
23. A circular laser for sustaining lasing cavity modes with an optical radiation of wavelength, λ, comprising:

a.) cavity structure means providing a surface of revolution, the surface thereby having a circular aspect;

b.) a reflective coating deposited on the surface of revolution, the coating providing a circular optical cavity, the optical cavity having a cavity interior with an interior index of refraction, the coating including at least one hundred thin film dielectric layers, the layers having alternating refractive indices, the alternating refractive indices at least as great as the interior index, the alternating refractive indices differing by less than 0.2, the coating providing greatest reflectance to the radiation at an angle-of-incidence, so that the coating is substantially reflecting to the radiation only at approximately the angle-of-incidence, such that the radiation only contributes to the modes when the radiation is propagating at approximately the angle-of-incidence;

c.) an optical gain medium in the cavity interior, the medium disposed for emitting the radiation into the modes; and,

d.) optical pumping means for excitation of the gain medium.



Received from < 520 799 7501 > at 3/3/03 3:13:41 PM [Eastern Standard Time]

FAX # 703-746-4313

NEW CLAIM

23. A circular laser for sustaining lasing cavity modes with an optical radiation of wavelength, λ, comprising:

a.) cavity structure means providing a surface of revolution, the surface thereby having a circular aspect;

b.) a reflective coating deposited on the surface of revolution, the coating providing a circular optical cavity, the optical cavity having a cavity interior with an interior index of refraction, the coating including at least one hundred thin film dielectric layers, the layers having alternating refractive indices, the alternating refractive indices at least as great as the interior index, the alternating refractive indices differing by less than 0.2, the coating providing greatest reflectance to the radiation at an angle-of-incidence, so that the coating is substantially reflecting to the radiation only at approximately the angle-of-incidence, such that the radiation only contributes to the modes when the radiation is propagating at approximately the angle-of-incidence;

c.) an optical gain medium in the cavity interior, the medium disposed for emitting the radiation into the modes; and,

d.) optical pumping means for excitation of the gain medium.

Received from < 520 799 7501 > at 3/3/03 3:13:41 PM [Eastern Standard Time]

(NEW CLAIM)

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b.) a reflective coating deposited on the surface of revolution, the coating providing a circular optical cavity, the optical cavity having a cavity interior with an interior index of refraction, the coating including at least one hundred thin film dielectric layers, the layers having alternating refractive indices, the alternating refractive indices at least as great as the interior index, the alternating refractive indices differing by less than 0.2, the coating providing greatest reflectance to the radiation at an angle-of-incidence, so that the coating is substantially reflecting to the radiation only at approximately the angle-of-incidence, such that the radiation only contributes to the modes when the radiation is propagating at approximately the angle-of-incidence;

c.) an optical gain medium in the cavity interior, the medium disposed for emitting the radiation into the modes; and,

d.) optical pumping means for excitation of the gain medium.

Q1

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TECHNOLOGY CENTER 2800

2828

Donald Hilliard, Ph.D
3050 North Fontana
Tucson, Arizona 85705

FAX TRANSMITTAL

DATE:			
TO:	**Paul Ip, S.P.E., Technology Center 2800**	**FROM:**	Donald Hilliard App't Pro Se, 09/839,254
FAX:	(703) 308-7722	**FAX:**	(520) 628-7131
TEL:	(703) 308-3098	**TEL:**	(520) 977-6423
CC:		**PAGES:**	cover + 1

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COMMENTS:

Sir,

This fax contains one sheet containing a new independent claim, concerning application # 09/839,254, for your consideration. This claim is intended for replacement of claim 1 of the application, which will be cancelled in the proposed amendment. Thank you for your help in this matter.

Very respectfully,

Don Hilliard
Applicant Pro Se